THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME VII MARCH 1898 NUMBER 3

THE CONCAVE GRATING FOR STELLAR PHOTOGRAPHY.

By CHARLES LANE POOR and S. ALFRED MITCHELL.

THE concave grating has proved a most powerful instrument for spectroscopic research, but heretofore it has not been successfully applied to stellar spectroscopy. Experiments are now being carried out at the Johns Hopkins University under the direction of Dr. Charles Lane Poor with the view of thoroughly testing the various methods of using the concave grating for astronomical purposes. The methods, originally suggested by Professor Rowland, were developed, and the formulæ derived by Dr. Poor, and the preliminary apparatus constructed under his direction: the experiments and the photographs were made by Mr. S. Alfred Mitchell. As some promising photographs have been obtained the following notes are now published in regard to methods and results.

There are two radically different methods of using the concave grating for stellar work.

First: In connection with an objective; the concave grating merely replacing the ordinary stellar spectroscope. This was tried by Professor Crew at the Lick Observatory in 1892, and a few results obtained.

Second: Direct; the grating is the objective and the spectroscope combined: the light from the star being reflected

directly from the grating to the photographic plate. In 1892 Dr. Poor had a rough apparatus made to test this method, and in 1892-3 he introduced this way of using the grating into his lectures on "Theory of Instruments." In the ASTROPHYSICAL JOURNAL of January 1896, is an article by Professor F. L. O. Wadsworth[1] in which this method is treated of and the equations given.

It is our purpose to test fully all the various methods so far as it is possible to do so at the Johns Hopkins University. Our best results, so far, have been obtained by the direct method, and this paper will be confined to an explanation of that method, to the derivation of the necessary formulæ and to a few notes in regard to the photographs already taken.

From the theory of the concave grating we have the general equation:

$$r = \frac{R\,\rho\cos^2\mu}{R\,(\cos\mu + \cos\nu) - \rho\cos^2\nu} \qquad (1)$$

(See Rowland, *American Journal of Science*, Vol. XXVI, Aug. 1883.)

In this equation ρ is the radius of curvature of the grating, and the axis of the grating is the line of reference for angular measurements; R and ν are the spherical coördinates of the source of light; r and μ those of the curve on which the spectra are brought to a focus.

This equation may be put into the following form:

$$r = \frac{\rho\cos^2\mu}{\cos\mu + \cos\nu - \dfrac{\rho}{R}\cos^2\nu} \qquad (2)$$

If now the source of light be placed at an infinite distance, then R is equal to infinity, and the equation (2) reduces to:

$$r = \frac{\rho\cos^2\mu}{\cos\mu + \cos\nu} \qquad (3)$$

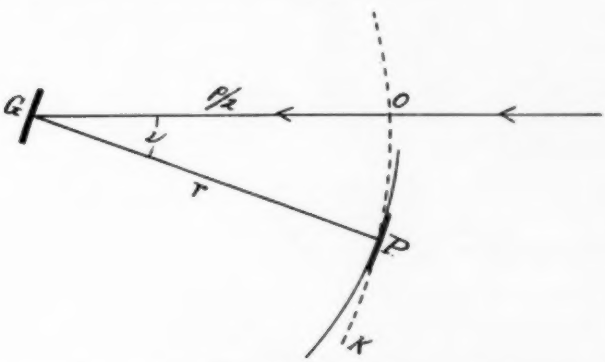
This is the general equation for the case under consideration.

[1] Professor Wadsworth's mathematical treatment on pp. 57-58 does not apply to our method of using the grating. He finds the variation in wave-length corresponding to changes in the angle of incidence of the light from the star. In our mounting this angle is constant, and within certain limits the resulting spectrum is "normal."

We may use the grating in a number of different ways, depending upon the position of the photographic plate and of the source of light in reference to the axis of the grating. One position is by far the best for general work, and in this preliminary note the formulæ for that case alone are given. The position is that in which the center of the photographic plate is on the axis of the grating. For this we have $\mu = 0$, and our general equation reduces to:

$$r = \frac{\rho}{1 + \cos\nu} \tag{4}$$

For any given value of ν, r is constant, and those parts of the spectra, for which we can assume $\cos\mu$ equal to unity, are brought to a focus on a circle whose radius is r as above given. The equation itself is that of a parabola, so that when ν is changed, μ being kept equal to zero, in order to bring different parts, or different orders, of spectra to the center of the plate, the value of r will vary and will correspond in value to that radius vector of the parabola which corresponds to the value of ν. This case is shown in the following figure:



G is the grating, *P* the photographic plate. The light comes in from the star in the direction of *OG*. The curve *OPK* is a parabola, *OG* being the half parameter and is equal to $\frac{1}{2}\rho$. For a constant value of ν those spectral lines on the photographic plate for which $\cos\mu$ can be assumed equal to unity, are brought to a focus on a circle whose radius is r.

To investigate this case fully we must return to the general equation (3). For a fixed value of ν, all the spectra are brought to a focus on the curve:

$$r = \frac{\rho \cos^2 \mu}{\cos \mu + \cos \nu}$$

in which $\cos \nu$ is constant. When μ is so small that its cosine may be taken as unity, this curve reduces to a circle, as above described.

By the theory of diffraction (Rayleigh, *Encyc. Brit.*, "Wave Theory of Light") we have:

$$\lambda = \frac{\omega}{N} (\sin \nu + \sin \mu) \tag{5}$$

where ω is the grating space and N is the order of the spectrum. From this we have at once:

$$\frac{d\lambda}{d\mu} = \frac{\omega}{N} \cos \mu \tag{6}$$

To find the change in wave-length as we pass along the focal curve, we have:

$$\frac{d\lambda}{ds} = \frac{d\lambda}{d\mu} \cdot \frac{d\mu}{ds}$$

and

$$\frac{d\mu}{ds} = \frac{1}{\sqrt{r^2 + \left(\frac{dr}{d\mu}\right)^2}}$$

Differentiating the equation of the focal curve, we find:

$$\frac{dr}{d\mu} = \frac{r \sin \mu - \rho \sin 2\mu}{\cos \mu + \cos \nu} = \phi(\mu) \tag{7}$$

whence substituting we finally find:

$$\frac{d\lambda}{ds} = \frac{\omega}{N} \cdot \frac{\cos \mu}{\sqrt{r^2 + \left[\phi(\mu)\right]^2}} \tag{8}$$

and this is the general formula for change in wave-length along the focal curve.

If now we put $\mu = 0$, this reduces to,

$$\frac{d\lambda}{ds} = \frac{\omega}{N} \cdot \frac{1}{r_0} \tag{9}$$

a constant. Hence at this point the spectrum is "normal."

Within the limits, therefore, to which we can take cos μ as equal to unity, the spectrum may be considered as normal.

For a grating of medium dispersion an entire spectrum will be practically normal, provided the center of the plate is on the axis of the grating; *i. e.*, μ equal zero for the middle of the spectrum.

In the grating used in our experiments the entire first order spectrum subtends an angle of about $6°$; and by computation we find from the above formulæ that the scales of different portions of the spectrum differ by less than three parts in a thousand. To be more exact, at a point $3°$ from the axis, the scale is smaller than at the center of the plate; the ratio of the latter to the former being 1.0025. On a plate of the solar spectrum as taken by the usual twenty-one foot Rowland mounting the scales of the middle and end differ by one and one-half parts in a thousand for the same variation of $3°$.

The advantages of this method of working are thus apparent. The photographic plate should be bent to conform with the focal curve as given by equation (3); within the above limits, however, this differs but little from a circle.

In order to test the above method a small Rowland concave grating with a ruled surface of 1×2 inches was used. The grating has a radius of curvature of one meter, and is ruled with 15,000 lines to the inch. The apparatus for mounting the grating is extremely simple, consisting of a light box clamped to the tube of the equatorial; the telescope being used merely as a finder. The light from the star falls directly on the grating, is diffracted and brought to a focus on a photographic plate. The grating is mounted in an ordinary holder which can be adjusted by side and back screws. The plate holder holds a plate 1×5 inches, bent as closely as possible to the proper radius. The holder is capable of adjustments, so that the plate and grating can be made parallel, in order to procure a normal spectrum. These adjustments are made with very little difficulty. The box is clamped to the telescope in such a way that the lines of the grating are parallel to the equator, and accordingly, by regulating the driving clock of the telescope to run a little too slow or too fast the spectrum can be made of any convenient width.

For our trials Sirius was the star principally used, and exposures ranged from ten minutes to one hour according to the width of the spectrum. All the photographs were made with the first order spectrum, and Seed's Gilt Edge plates were used.

The spectra arè about 5^{cm} long, and vary in width from $0^{mm}.1$ to $1^{mm}.5$, depending upon the exposure and the rate of the clock. Details of a few specimen plates follow:

Sirius. Nov. 27. Exposure 40 minutes, width $1^{mm}.5$, 8 hydrogen bands and H and K lines.

Capella. Dec. 9. Exposure 40 minutes, width $0^{mm}.2$. F, G, *h*, H, K, and about 50 fine lines.

Procyon. Dec. 15. Exposure 40 minutes, width $0^{mm}.15$, 6 hydrogen bands, H and K and about 20 fine lines.

Rigel. Dec. 28. Exposure 85 minutes, width $0^{mm}.1$, 14 hydrogen bands, H and K, and 6 other lines.

Sirius. Jan. 3. Exposure 40 minutes, length 5^{cm}, width $0^{mm}.1$, 16 hydrogen bands, H and K lines and 15 other distinct fine lines.

The accompanying plate gives the enlargement of two of our photographic plates of Sirius. The lower spectrum is the enlargement of one taken December 15, 1897, showing 13 hydrogen lines, H, K, and ten others. The upper spectrum is the enlargement of the plate taken January 3 (noted above). Since our original spectra are extremely narrow, considerable difficulty is experienced in widening out the spectra without introducing spurious lines. Although some of the finer lines are spurious, the plate shows the general character of our photographs in that it shows clearly the hydrogen lines, K, and many other lines which can be easily identified.

All these experiments were carried on in the Observatory, which is on the fifth floor of the Physical Laboratory, and is subject to the jar of street cars and city traffic as well as to dust and to the glare of electric lights. We are confident that much better results will be obtained under better conditions, and think that this method promises to become of great value to stellar spectroscopy.

JOHNS HOPKINS UNIVERSITY,
January 5, 1898.

ON CERTAIN NEW RESULTS RELATING TO THE PHENOMENA DISCOVERED BY DR. ZEEMAN.

By M. A. Cornu.

Successive improvements in the method of observing the phenomena discovered by Dr. Zeeman have led me to certain results which are not in agreement with the earlier observations, and which may modify our ideas on the mechanism of these phenomena.

The general method of conducting the experiment is that which I have previously described: the luminous source (oxy-hydrogen flame saturated with saline vapors, induction spark, etc.) is placed between the two poles of a powerful electromagnet, and the image of this source is projected upon the slit of a spectroscope of high dispersion, provided with the necessary doubly refracting appliances.

1. *Observations in the direction of the lines of force.*

My earlier conclusions regarding the resolution of the ray of ordinary light into two circularly polarized rays are not affected.[1] But micrometric measures have shown that the magnitude of this doubling does not depend exclusively on the wave-length of the line observed; the observations may be summarized as follows:

The effect of the magnetic field on the period of vibration of the radiations of a luminous source seems to depend not only upon the chemical nature of the source, but also upon the nature of the group of spectral lines to which each radiation belongs, and on the part which it plays in this group.

There thus remains little hope of the possibility of expressing the magnitude of the magnetic doubling of the lines of a given spectrum as a simple function of the wave-length, as had been hoped at the outset.[2] It is, however, this very point of view of

[1] M. A. Cornu, this Journal, **6**, 378, December 1897; *C. R.*, **125**, 555.

[2] H. Becquerel, *C. R.*, **125**, 679.

the existence of essential differences among the lines of the same spectrum—differences already recognized under various circumstances (spontaneously reversible lines,[1] hydrogen groups,[2] etc.)—which has led me to pursue the detailed study of the Zeeman phenomenon as offering a new means of bringing to light those families of lines, the existence of which certain optical peculiarities have already led us to suspect.

As a matter of fact, the observation of groups well known by their regular geometric arrangement reveals under the action of magnetism peculiarities analogous to their unequal facility of spontaneous reversal. Thus visual observations of the magnesium group *b* and photographs of the group of three blue lines of zinc show that the magnitude of the magnetic doubling of their components increases rapidly with the refrangibility, while the difference in wave-length of the various lines is insignificant.

Contrary to what one would be led to expect from the experiments of Messrs. Egoroff and Georgiewski, it is the most easily reversible line which shows the least doubling effect.

2. *Observations in the direction normal to the lines of force.*

The principal result obtained in this case profoundly modifies in an important particular the early conclusions of Messrs. Zeeman and Lorentz.

(1) *Under the influence of the magnetic field in the direction normal to the lines of force a single spectral line becomes* QUADRUPLE (and not TRIPLE, as has been previously announced). *The two outer lines are polarized parallel to the lines of force, the two intermediate lines perpendicular to this direction.*

(2) *The quadruplet thus formed is symmetrical with reference to the original line, and the separation of the two similarly polarized lines is sensibly proportional to the intensity of the magnetic field.*[3]

[1] M. A. CORNU, *C. R.*, **123**, 332.

[2] M. A. CORNU, *C. R.*, **100**, 1181.

[3] I have also found that for equally intense magnetic fields the distance between the two lines polarized parallel to the lines of force is sensibly equal to the distance between the circularly polarized lines; but the precision of the optical or magnetic measures is still insufficient to render possible a certain demonstration of this equality.

It is the improvement of the optical apparatus rather than the increased strength of the magnetic field which has permitted me to effect the doubling of the central line of Zeeman's *triplet;* this doubling must already have been seen by many observers; but imperfect images have caused it to be mistaken for a simple *reversal.* Moreover, it is usually very small and always very unequal, varying with the line observed, even in very compact groups.

The most striking example, which is at the same time the easiest to observe, is that offered by the sodium group D_1, D_2.

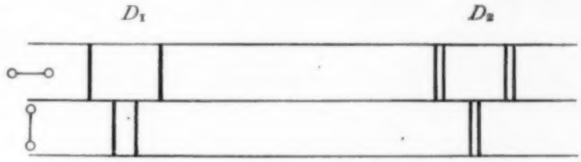


FIG. 1.

The line D_1 (Fig. 1), which is the narrower and the less refrangible of the two, is transformed into a well-defined *quadruplet,* the two intermediate lines being separated by half the amount of the two outer ones. The line D_2, which is broader and more easily reversible, becomes a triplet, because the central line remains single. It is true that there is some indication of a faint dark line in the middle of this central component; but as the two other oppositely polarized components have the same appearance, the doubling remains uncertain. Thus the essential difference in nature between D_1 and D_2, long ago exhibited by their unequal facility of spontaneous reversal, is demonstrated here by a well-defined characteristic, *i. e.*, unequal separation of the central components. This separation is very great in D_1, very small in D_2; the distance between the exterior components is, on the contrary, sensibly the same for both lines. May one not be permitted to suppose that the action of the magnetic field affects one of the most essential elements of the mechanism concerned in the genesis of these radiations?

The magnesium group b, composed of three lines b_1, b_2, b_4,[1] is equally instructive. One might expect to see the narrowest line transformed into a quadruplet; but this is not the case, it becomes a simple triplet. The intermediate line b_2, on the contrary, is sharply separated into four. The first line b_1, the most easily reversible of the three, is also separated into a quadruplet, but it is too diffuse to show the phenomenon in a satisfactory way.

The green line of thallium is also too broad to show satisfactorily the doubling of the central line. The green line (No. 4) of cadmium also separates into four, but an intense magnetic field is required to show this subdivision well.

If one were inclined to be in doubt, from the few observations made in the direction of the lines of force, regarding the special effect of the magnetic field on the radiations emitted, the results just cited, obtained in the direction normal to these lines, must remove all question. There is, moreover, no reason to fear errors due to imperfect adjustment of the optical apparatus; in fact, in the direction normal to the lines of force I have utilized as a separating apparatus only a small rhomboid of Iceland spar. As for the magnetic field, the uniformity of which is never perfect, I have convinced myself (by giving to the pole-pieces the most diverse forms) that if the mean intensity of the field varies with the form of the poles the relative distance of the components of the quadruplet nevertheless remains unchanged; the phenomenon thus in no way depends upon the particular form of the equipotential surfaces of the field.[2]

It might finally be objected, not without some reason, that the small scale of the deviations obtained up to the present time renders the interpretation of the appearances very uncertain.

[1] The line b_3 in the b group of the solar spectrum belongs to nickel.

[2] In this connection I have found a very curious method for rendering *visible* the equipotential magnetic surfaces in the neighborhood of the pole-pieces in very intense fields; I do not know whether it is known, but it is, in any case, very convenient. It consists in causing the uncondensed spark of a powerful induction coil to pass between two well-separated metallic electrodes placed in the field to be explored. The line of sparks is not deviated, but the violet halo is *blown* aside; it spreads out on one side

But this objection is not applicable to my experiments; thanks to the various precautions resulting from successive attempts, I obtain very sharp and brilliant images separated by well-defined dark intervals.[1]

This result is due to the use of the excellent plane grating which was employed in my solar spectroscopic studies,[2] and which I owe to the kindness of Professor Rowland. With this I have constructed a spectroscope of high dispersion,[3] in which the third order spectrum is particularly bright, so that the observed deviations are relatively large. I give below measures obtained in an observation made with a magnetic field of about 13,000 C. G. S. units.

Distance between the outer lines of the quadruplet D_1 . . $0^r.54$ of the ocular micrometer.

Distance between the interior lines of the quadruplet D_1 . . . 0.26

Distance between the lines D_1, D_2 in their ordinary state . 3.61

The pitch of the micrometer screw is half a millimeter.

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only in the form of a luminous mantle, veined in concentric curves, which closely follow the form of the equipotential surface, passing through the point where the discharge occurs, and its area increases with the intensity of the magnetic field at this point.

This mantle changes from one side to the other when either the direction of the induced current or that of the lines of force is reversed.

With easily volatile electrodes (thallium, metallic sodium, etc.), the phenomenon is especially brilliant.

If the electrodes are very close together a second mantle, symmetrical but narrower, appears on the other side, the whole forming a butterfly with unequal wings; it is evidently due to the discharge of the induced low tension direct current.

[1] As a particular instance I may mention that the sodium lines, D_1, D_2, are obtained by varying the proportion and the pressure of the oxyhydrogen gases impinging upon a globule of sodium glass; with a little skill one succeeds in producing at will all the known spectral appearances, lines faint and diffuse, lines bright and well-defined, with or without reversal.

In the induction spark passing between two poles of metallic sodium, the metal does not take fire even with a strong condensed discharge; but the lines are bright and reversed, and the quadruplet appears dark on a bright field.

[2] *Ann. Chim. et Phys.*, (6) **7**, 5.

[3] *Jour. de Phys.*, (2) **2**, 53. The spectroscope described in this article gave excellent results, but by replacing the flint prism with the grating the definition was considerably improved.

The greatest distance between the components separated by the magnetic action thus amounted to nearly one-sixth of the distance between the lines D_1 and D_2.

Remark.—This unexpected quadrupling of the vibratory period of a monochromatic source, normal to the lines of force, at first sight contradicts the simplicity of the elegant kinematic interpretation corresponding to the formation of the triplet, which led to the conclusion that the amplitude of vibration of the radiations is not modified in the direction of the lines of force. But on reflection I am convinced that the new experimental result, which we are forced to recognize, nevertheless agrees perfectly with the idea which may be formed of a line of magnetic force, which is defined by a *vector* or *directed quantity;* the properties of the complex system which it represents thus depend upon the direction in which it is directed. Now the amplitude of vibration is also a directed quantity; it is thus natural that the reciprocal influence of two parallel elements, both characterized by vectors, may be of two kinds according as the vectors in play are of the same or contrary sign. This is evidently a somewhat abstract argument, but one which nevertheless imposes the necessary condition. The resultant effect may be *nil;* this is what appeared from the earlier imperfect observations; but not being *nil,* it necessarily has two equal values of contrary sign. This is exactly what the new observations show, that is to say, a variation of period symmetrical on either side of the original period.

If the kinematic interpretation of the phenomenon becomes a little more complex, it at the same time acquires a very suggestive symmetry regarding the constitution of the magnetic field.

Like the vibratory components normal to the lines of force, the component parallel to this direction is doubled and the periods of the two parts are altered by quantities respectively equal, of contrary sign, and proportional to the intensity of the field.

From what precedes it is evident how many important questions regarding the relationship of electricity with light are raised

by these new experiments. Although the observations are very delicate and still very incomplete, I have thought it desirable to make them known, with the intention of pursuing them when the necessary means which I hope to have at my disposal shall permit me to increase still further the magnitude of the effects and consequently the precision of the measures.

PARIS, January 21, 1898.

RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE SECOND HALF OF 1897.

By P. TACCHINI.

I GIVE below a résumé of the solar observations made at the Royal Observatory of the Roman College during the second half of 1897. The results for the spots and faculæ are brought together in the following table:

1897	Number of days of observation	Relative frequency		Relative areas		Number of spot groups per day
		of spots	of days without spots	of spots	of faculæ	
July	31	8.16	0.00	31.3	66.1	2.5
August	28	6.42	0.00	31.1	73.8	1.6
September	28	14.43	0.00	43.9	65.4	4.7
October	27	3.82	0.22	5.6	93.1	1.8
November	22	2.05	0.50	4.1	73.1	0.5
December	21	8.71	0.05	42.7	75.0	2.1

The season was very favorable, and it will be seen that the spots have continued to decrease, particularly in area. A rather marked minimum occurred in October and November, after the September maximum; a similar fluctuation may be found in the preceding series for the months of April, May and June.

For the prominences the following results have been obtained:

1897	Prominences			
	Number of days of observation	Mean number	Mean height	Mean extent
July	30	2.57	29″.9	1°.1
August	27	3.96	36 .1	1 .5
September	26	5.23	37 .2	1 .3
October	20	4.90	37 .7	1 .3
November	18	4.95	39 .2	1 .7
December	17	3.00	39 .0	1 .3

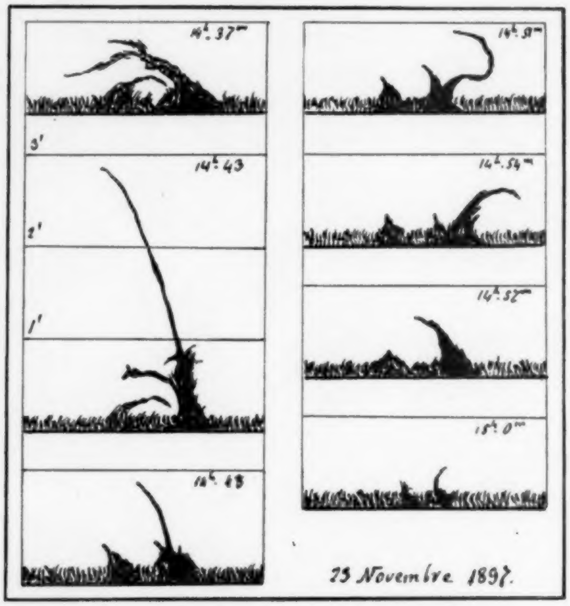
Comparing these numbers with the results obtained for the first half of the year we conclude that the prominences have remained practically stationary in activity.

The results for the distribution in latitude of the various phenomena are given by quarters and by zones in the following table:

1897 Latitude	Prominences		Faculæ		Spots	
	Third quarter	Fourth quarter	Third quarter	Fourth quarter	Third quarter	Fourth quarter
90°+80°	0.003	0.008				
80 +70	0.006	0.004				
70 +60	0.000	0.020				
60 +50	0.086	0.096				
50 +40	0.089 } 0.390	0.076 } 0.448	0.007	0.004		
40 +30	0.027	0.044	0.036	0.017		
30 +20	0.068	0.080	0.080 } 0.396	0.054 } 0.480		
20 +10	0.057	0.072	0.135	0.161	0.104 } 0.271	0.162 } 0.676
10 + 0	0.054	0.048	0.138	0.244	0.167	0.514
0 −10	0.140	0.104	0.215	0.219	0.373 } 0.729	0.243 } 0.324
10 −20	0.128	0.120	0.236	0.198	0.354	0.081
20 −30	0.116	0.100	0.109 } 0.604	0.095 } 0.520		
30 −40	0.030	0.032	0.029	0.004		
40 −50	0.092 } 0.610	0.044 } 0.552	0.015	0.004		
50 −60	0.083	0.132				
60 −70	0.012	0.016				
70 −80	0.006	0.004				
80 −90	0.003	0.000				

The prominences have continued to show themselves in almost all zones, with a maximum of frequency between the equator and the parallel of −20°. But it should be remarked that

two secondary maxima occurred at the same distance from the equator, *i. e.*, in the zones ($\pm 40° \pm 60°$). The spots have been confined within the region between the equator and $\pm 20°$, as was



the case during the second quarter. The only eruption observed during the entire period of six months was that of November 23, on the west limb, at latitude $+8°.2$. A very bright jet suddenly formed and rose to a height of 168″, disappearing in twenty minutes, as is indicated in the figures.

ROME, January 31, 1898.

ON THE ARC-SPECTRA OF THE ELEMENTS OF THE PLATINUM GROUP. II.

By H. KAYSER.

IV. RHODIUM.

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2308.88	2	2432.755	1	2488.547	1
2318.432	2	2433.346	0	2489.986	0
2319.173	2	2436.974	0	2490.860	3
2328.737	2	2437.174	2	2492.395	2
2334.762	1	2439.338	0	2493.733	1
2345.597	1	2440.427	2	2494.604	4, u
2368.380	3	2442.830	0	2499.095	2, u
2369.654	2	2443.221	0	2500.668	2
2370.642	2	2443.812	0	2500.740	0
2382.969	2	2444.337	4, u	2501.115	1
2383.490	2	2444.843	0	2502.546	2
2384.751	2	2445.714	2	2502.843	1
2386.222	4	2448.378	0	2503.458	0
2386.489	0	2448.923	2	2503.939	1
2396.617	0	2450.660	4	2504.384	4, u
2399.044	0	2453.898	0	2505.189	2
2406.472	0	2455.521	0	2505.758	2
2407.974	2	2455.788	2	2507.342	0
2408.100	0	2456.277	1	2508.743	0
2408.275	1	2459.004	2	2509.788	2
2408.745	0	2459.237	1	2510.747	2
2409.626	0	2461.120	2	2511.133	2
2410.348	0	2463.670	4, u	2512.180	2
2412.613	1	2469.203	1	2513.464	2
2414.433	0	2470.486	2	2515.833	2
2414.662	0	2470.860	0	2518.561	0
2414.927	3	2471.561	2	2520.623	2
2417.523	0	2472.571	2	2522.988	2, u
2418.718	3	2473.199	2	2525.221	0
2420.271	2	2474.116	0	2526.092	1
2420.947	0	2474.677	1	2526.244	2
2421.060	2	2475.097	4	2526.744	0
2422.237	0	2475.749	0	2530.284	0
2424.021	2	2475.978	0	2531.053	0
2424.521	0	2477.618	0	2531.369	0
2427.193	3	2480.596	0	2531.920	2
2427.777	2	2480.921	0	2532.743	2
2429.053	2	2481.686	0	2533.687	2
2429.268	0	2483.423	2, u	2534.170	2
2429.610	2	2485.688	2	2534.682	0
2431.936	2	2487.581	4	2536.803	4

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2537.155	3	2607.831	2	2666.498	2
2537.721	2	2608.639	2	2667.317	0
2539.860	4, u	2609.266	0	2667.453	0
2541.096	2	2610.156	0	2669.419	0
2543.648	0	2612.315	0	2671.144	4
2544.317	2	2613.145	0	2671.529	1
2545.794	4	2613.689	4, u	2674.059	2
2547.366	0	2615.735	2	2674.287	2
2548.679	2	2616.178	2	2674.525	2
2551.289	2	2618.596	3	2676.200	4
2553.426	0	2621.099	2	2676.573	2
2555.010	0	2622.661	4	2680.379	2
2555.449	4	2622.756	1	2680.717	4
2556.172	1	2624.821	0	2681.873	3
2558.714	4	2624.948	0	2682.624	2
2560.322	2	2625.309	2	2683.660	0
2562.741	0	2625.496	1	2684.301	2
2564.900	0	2625.973	3	2685.551	0
2565.888	2	2626.776	2	2686.608	4
2566.137	2	2627.042	0	2687.015	4
2566.960	2	2628.222	0	2687.411	2
2567.374	4	2630.003	2	2688.173	2
2569.171	0	2630.509	2	2689.022	0
2570.206	2	2633.373	2	2689.716	0
2573.577	2	2633.523	2	2692.390	2
2574.332	2	2634.605	0	2692.463	2
2574.751	2	2635.082	4	2693.726	2
2576.330	2	2635.407	1	2694.405	4
2579.487	2	2636.744	1	2697.955	2
2579.650	0	2637.484	0	2700.384	2
2580.043	0	2638.388	0	2700.688	1
2581.100	2	2638.839	2	2702.158	2
2581.790	0	2639.097	0	2702.337	2
2584.016	1	2639.327	0	2702.621	0
2586.897	2	2642.857	0	2703.820	6
2587.245	2	2643.077	4	2705.059	0
2587.353	0	2643.691	2	2705.718	3
2588.545	0	2647.375	4	2706.135	2
2589.892	1	2648.681	2	2707.320	2
2592.247	0	2649.686	1	2707.896	0, u
2596.134	0	2650.985	0	2709.613	3
2597.014	3	2651.973	0	2714.499	4
2597.484	0	2652.750	5	2714.881	0
2597.774	2	2656.000	2	2715.149	2
2598.166	2	2658.515	0	2715.399	2
2599.352	0	2659.098	2	2716.645	0
2601.926	0	2659.573	2	2716.912	2
2603.500	4	2659.937	1	2717.606	3
2605.807	2	2663.389	0	2718.111	0
2606.540	4	2663.764	2	2718.648	2

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2720.235	3	2794.587	0	2852.809	0
2720.622	3	2795.366	1	2854.237	0
2722.243	2	2795.824	2	2854.848	2
2722.389	0	2796.743	3	2855.273	4
2725.961	0	2799.536	0	2859.735	2
2726.934	0	2799.705	0	2859.908	3
2729.034	6	2800.021	0	2860.208	0
2729.611	0	2801.674	3	2860.774	3
2731.874	0	2802.113	0	2860.886	4
2732.261	0	2804.020	2	2861.877	0
2734.906	2	2805.908	2	2862.572	0
2736.860	3	2806.212	1	2863.057	6
2737.509	2	2807.270	2	2864.517	4
2737.717	2	2809.853	0	2865.755	2
2738.359	2	2810.999	3	2867.973	1
2739.845	1	2814.817	0	2868.400	2
2740.027	1	2816.979	1	2869.746	0
2740.304	2	2819.367	2	2870.108	2
2740.487	0	2819.742	3	2870.551	2
2740.647	2	2820.946	3	2871.489	5, u
2743.568	0	2821.620	1	2873.104	0
2751.140	0	2822.850	0	2873.742	4
2751.450	2	2822.979	2	2874.115	2
2752.941	2	2823.504	2	2874.507	0
2754.845	0	2823.756	0	2875.764	2
2757.005	1	2823.988	0	2876.592	0
2760.541	2	2826.532	4	2878.139	0
2762.311	0	2826.798	4	2878.770	4
2762.938	2	2827.433	4	2879.628	0
2764.909	2	2828.259	0	2880.775	1
2767.832	4	2829.421	2	2880.912	2
2768.336	4	2829.664	2	2881.400	2
2770.277	1	2831.398	0	2882.497	4
2771.615	4	2832.893	2	2884.683	2
2773.397	2	2833.981	1	2885.364	0
2774.557	2	2834.233	4	2886.112	4
2775.869	2	2834.990	1	2887.082	0
2778.162	4	2835.671	1	2888.986	0
2778.967	3	2836.799	4	2889.222	4
2779.654	3	2838.425	2	2889.623	1
2780.439	3	2839.666	0	2889.962	4
2781.184	1	2841.909	4, U	2892.320	4
2783.140	5	2842.270	4, u	2892.817	0
2785.920	0	2844.463	4, u	2893.142	1
2786.934	2	2844.917	0	2895.823	1
2790.493	2	2845.868	2	2897.171	0
2790.872	2	2849.461	2	2897.806	0
2791.270	4	2850.608	1	2899.800	2
2792.886	2	2851.526	0	2900.080	4
2794.020	2	2852.459	1	2902.975	0

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2903.428	2	2961.805	2	3036.483	0
2903.960	0	2963.664	2	3038.583	2, u
2904.440	0	2965.018	0	3043.586	0
2905.106	2	2965.801	0	3045.887	3
2907.335	3	2968.790	6	3046.304	2
2907.835	1	2970.807	1	3046.871	4
2909.837	0	2971.741	0	3047.440	0
2910.281	4	2974.156	3	3048.095	2
2912.746	4	2975.935	2	3049.003	0
2913.185	0	2977.809	5	3049.334	2
2913.474	0	2981.238	2	3049.919	0
2913.715	2	2982.514	3	3050.050	0
2914.114	4	2983.194	4	3050.842	2, u
2914.691	0	2984.135	0	3051.780	2
2915.534	4	2984.593	0	3053.988	2
2917.028	0	2986.330	7	3054.980	0
2920.296	1	2987.117	5	3055.755	0
2921.229	0	2987.568	3	3056.452	0
2923.239	4	2988.487	0	3057.996	4
2924.140	4	2988.977	0	3058.974	1
2926.160	0	2989.302	0	3059.473	2
2926.322	0	2990.048	2	3060.001	0
2926.953	0	2990.158	0	3061.782	2
2927.062	0	2991.881	2	3062.544	0
2928.559	0	2995.828	0	3063.700	1
2929.256	4	3001.582	0	3065.800	0
2932.065	4	3004.565	5	3066.333	0
2934.988	0	3005.929	2	3066.475	0
2937.285	2	3009.103	1	3067.395	6
2938.403	2	3010.369	0	3069.034	2
2939.588	2	3011.021	0	3070.467	1
2940.175	0	3014.352	2	3071.134	3
2941.246	3	3015.960	0	3071.716	1
2942.116	0	3016.930	1, u	3073.550	0
2946.042	2	3017.225	1	3074.806	2
2948.388	0	3018.194	0	3076.736	2
2949.475	1	3019.569	2	3078.905	0
2950.023	3	3019.664	2	3080.449	0
2951.957	1	3019.928	0	3081.714	0
2955.395	2	3022.117	0	3084.078	4
2955.541	2	3022.673	0	3085.790	2
2955.942	0	3023.164	0	3087.180	0
2956.229	0	3024.018	3	3087.534	4
2956.406	1	3025.517	2	3088.428	2
2958.504	0	3027.053	2	3089.480	0
2958.899	4	3027.817	1	3089.775	0
2959.478	1	3028.545	4	3090.506	2
2959.769	4	3028.975	0	3091.840	0
2960.686	0	3031.573	0	3093.592	0
2960.773	0	3034.474	0	3094.691	2

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3096.722	0	3177.020	0	3255.104	4
3096.834	1	3177.201	4	3258.352	0
3099.567	0	3178.517	4	3259.994	0
3102.634	4	3179.833	5	3260.938	2, u
3105.110	4	3181.330	3	3263.280	8
3105.756	1	3182.519	0	3263.924	2
3108.405	2	3183.012	0	3264.313	0
3115.027	5	3183.558	0	3266.511	1
3119.846	0	3184.485	0	3267.605	1
3120.714	0	3185.702	5	3268.597	5
3121.381	0	3187.265	0	3270.702	3
3121.879	6	3187.740	0	3271.748	8
3123.818	6	3187.998	1	3274.908	4
3124.508	2	3188.408	1	3276.122	4
3125.000	0	3189.162	5	3278.620	2
3126.990	2	3190.466	3	3280.680	4, r
3130.918	4	3191.313	6	3281.827	4
3134.047	1	3192.112	0	3282.932	0
3134.710	0	3192.336	0	3283.705	4, r
3135.590	2, u	3193.633	1	3284.151	0
3137.450	4	3193.963	2	3285.964	2
3137.825	5	3194.671	4	3286.520	4
3138.506	1	3197.257	4	3288.159	2
3140.355	0	3199.979	1	3289.274	5
3140.549	1	3206.202	4	3289.739	5
3140.963	0	3207.390	2	3292.531	0
3141.314	0	3211.504	3	3293.012	0
3145.518	1	3212.667	0	3293.533	0
3145.734	2	3214.440	4	3294.400	5
3146.327	0	3214.628	0	3294.843	1
3147.274	0	3214.984	4	3296.847	4
3147.736	4	3218.009	4	3297.409	2
3148.350	1	3218.395	4	3297.667	0
3149.580	0	3218.655	0	3299.066	2
3149.978	0	3220.893	2	3300.133	0
3150.385	4	3221.193	0	3300.479	2
3152.724	6	3221.422	1	3300.604	4
3159.453	0	3221.589	0	3301.820	0
3155.489	6	3232.627	4	3303.474	0
3158.063	2	3233.440	0	3303.872	0
3159.001	2	3234.656	0	3304.258	2
3159.354	2	3235.910	2	3305.298	4
3162.388	1	3237.781	4	3307.091	1
3162.608	0	3240.644	0	3307.474	0
3163.551	1	3240.998	0	3308.067	3
3167.072	0	3241.602	0	3309.663	2
3170.379	0	3242.111	0	3314.665	2
3171.625	2	3242.820	1	3316.670	0
3172.392	4	3250.151	2	3323.232	6, r
3176.666	0	3253.457	2	3331.223	4

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3331.393	4	3399.823	7	3485.031	2
3332.648	1	3401.109	3	3487.366	3
3335.328	0	3403.247	0	3487.621	3
3336.842	0	3404.021	2	3491.216	3
3338.672	7	3406.690	5	3491.365	3
3340.987	0	3407.387	2	3494.585	5
3343.036	5	3407.884	2	3498.887	7
3343.573	2	3408.990	0	3502.686	8, r
3344.337	5	3410.074	0	3505.559	4
3347.437	1	3410.625	1	3507.471	4, r
3347.660	0	3412.425	6	3508.754	1
3352.510	2	3415.824	0	3509.444	3
3353.834	2	3416.901	0	3511.696	3
3354.853	4	3420.307	4	3511.942	4
3356.670	1	3422.430	3	3513.258	4
3357.560	0	3423.699	0	3519.690	2
3357.980	2	3424.533	4	3525.805	2
3358.962	0	3428.559	2	3528.183	7, r
3360.043	6	3432.234	2	3538.269	3
3360.952	8	3435.037	10, r	3538.409	3
3362.321	5	3440.675	4	3542.068	4
3363.382	0	3442.243	0	3544.122	5
3364.281	0	3442.781	4	3549.681	5
3365.138	0	3443.001	2	3550.165	0
3365.652	0	3446.202	0	3564.290	2
3368.518	6	3447.897	6	3590.688	1
3368.914	3	3448.715	5	3593.685	3
3369.824	5	3450.437	5	3594.054	0
3372.379	7	3451.294	4	3596.183	4
3372.672	2	3454.617	0	3596.343	4, r
3372.930	0	3455.369	4	3597.300	6, r
3373.879	0	3455.595	4	3598.057	3
3375.735	0, u	3456.284	0	3600.911	4
3376.017	0	3457.219	5	3606.029	5
3377.275	5	3458.070	6	3608.246	4
3377.742	2	3458.815	0	3612.621	5, r
3377.850	4	3459.375	3	3614.099	1
3380.775	4	3462.191	5, r	3614.674	1
3381.208	0	3469.355	0	3614.934	4
3381.578	4	3469.774	5	3620.621	5
3385.919	6	3470.505	1	3626.759	7
3387.174	2	3470.817	4, r	3627.342	4
3387.960	0	3472.402	5	3627.958	4
3389.340	3	3472.994	0	3639.684	6
3390.608	1, u	3474.939	5, r	3643.301	0
3391.847	2	3477.354	1	3644.363	0
3391.935	2	3478.646	2	3651.516	2
3392.230	1	3479.064	4, r	3655.044	5
3395.014	3	3480.658	0	3658.148	8, r
3396.956	8, r	3484.186	4	3661.760	2

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3662.027	3	3856.167	0	4177.780	1
3666.381	7	3856.663	4, r	4196.672	3
3667.070	4	3865.291	1	4206.770	2
3674.924	5	3870.140	2	4211.306	5, r
3681.205	6	3872.534	0	4218.142	2
3690.872	4, r	3877.470	2	4228.002	0
3691.481	2	3888.475	2	4230.354	2
3692.506	10, r	3891.953	0	4244.598	4
3695.105	2	3904.362	2	4258.608	1
3695.674	5	3905.423	1	4270.696	2
3698.415	3	3912.971	2	4273.578	4
3698.758	5	3913.657	4	4276.962	2
3699.461	2	3922.340	4	4278.744	3
3701.057	8, r	3934.384	4, r	4288.883	7
3713.156	4, r	3935.123	2	4296.926	4
3713.593	3	3935.982	4	4308.982	2
3714.989	4	3942.862	5	4315.126	2
3725.091	2	3953.214	2	4325.584	0
3735.429	4	3958.313	4	4336.181	1
3737.448	4	3959.006	5, r	4342.608	1
3744.325	4	3964.688	4	4345.247	2
3748.383	5	3968.320	2	4345.629	3
3754.269	4	3975.472	5	4349.336	2
3754.441	3	3976.240	2	4362.393	0, u
3755.290	1	3984.555	5	4373.212	5
3755.748	2	3995.768	4	4374.976	7, r
3760.554	2	3996.313	5	4376.350	1
3765.232	5, r	4023.302	5	4380.097	5, u
3770.130	4	4026.089	1	4388.224	1
3771.779	2	4048.572	3	4402.725	1
3775.864	2	4049.188	3	4410.449	0
3778.279	4	4053.602	3	4420.178	0, u
3788.633	5	4056.491	3	4421.383	0
3793.366	4, r	4077.739	4	4423.835	1
3799.466	4, r	4080.690	1	4424.215	3
3806.071	4	4081.961	2	4433.495	4
3806.920	4	4082.942	5	4484.015	2
3809.655	2	4084.442	2	4492.644	4
3812.599	2	4087.950	4	4503.955	4
3815.169	1	4088.646	4	4506.815	1
3816.611	1	4097.690	5	4528.904	5
3817.524	0	4116.496	4	4530.763	3
3817.990	0	4119.855	4	4544.447	4
3818.345	5	4121.870	4	4551.828	6
3822.397	4, r	4125.063	2	4557.343	4
3827.505	0	4129.080	6	4558.897	4
3828.623	2	4135.448	4, r	4561.062	5
3833.733	0	4137.008	0	4565.373	4
3834.016	5, r	4154.495	2	4568.538	2
3834.893	2	4158.615	1	4569.181	6

IV. RHODIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
4570.489	2	4918.953	2	5237.918	1
4571.466	4	4919.823	2	5248.918	0
4572.794	2	4922.633	2	5251.549	2, u
4599.553	0	4944.975	2	5259.382	3
4601.792	2	4960.318	1	5268.092	0
4608.294	2	4961.012	0	5269.429	3
4620.059	5	4963.831	4	5280.250	2
4626.105	1	4966.511	2	5292.279	4
4634.017	4	4977.869	4	5314.911	3
4639.526	4	4985.107	2	5329.571	0
4643.337	6	4996.012	0	5329.890	4
4666.261	2	4997.919	1	5331.237	2
4675.187	7	5012.538	0	5336.794	0
4677.532	4	5025.692	1	5339.845	0
4683.093	3	5028.492	2	5349.463	2
4689.610	1	5046.583	2	5354.573	7
4696.463	1	5057.576	2	5356.638	3
4704.230	5	5064.475	4	5359.850	0
4707.108	1, u	5073.607	0	5364.290	0
4719.545	2	5085.676	4	5369.470	1
4721.148	6	5088.949	0	5379.275	5
4724.483	2	5090.795	5	5381.683	0
4731.333	1, u	5110.115	2	5384.214	0
4745.276	6	5120.824	1	5390.622	5
4750.007	0	5130.903	2	5404.898	4, u
4755.717	4	5145.110	2	5408.972	2
4770.938	3	5155.691	5	5423.483	2, u
4771.687	2	5157.224	2	5424.910	4
4777.304	2	5157.814	5	5425.636	4, u
4791.164	3	5160.464	0, u	5431.813	2, u
4791.640	0	5165.561	0	5432.224	2, u
4794.364	0	5174.883	0	5439.783	4
4798.829	4	5176.110	6	5441.547	4, u
4801.517	1, u	5177.396	3	5444.508	2, u
4803.393	0	5178.311	0	5445.424	4, u
4810.645	6	5184.342	4	5468.288	3, u
4813.678	1	5185.172	1	5468.921	2, u
4817.233	0	5187.088	0	5471.040	5, u
4833.627	0	5193.276	7	5475.318	2, u
4842.556	4	5197.697	1	5480.997	0
4844.145	6	5203.468	2	5481.602	2, u
4851.777	6	5207.099	3	5484.421	4, u
4856.614	0	5211.637	4	5492.048	2, u
4861.497	2, u	5212.866	4	5497.197	0
4861.808	0, u	5213.491	2	5503.776	2, u
4865.922	4	5214.913	3	5504.845	4, u
4888.045	0	5222.783	4	5534.074	1, u
4898.022	1	5225.706	1	5535.235	5, u
4908.744	2	5230.752	4	5542.260	0
4913.649	2	5237.284	5	5544.797	6, u R

IV. RHODIUM—*continued*.

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
5555.288	0	5659.924	2, u	5797.668	2
5556.968	3	5686.543	4	5803.482	2
5557.364	1, u	5695.823	1′	5807.058	4
5568.495	0	5700.628	4, u	5821.991	2
5595.053	2, u	5708.930	0, u	5831.730	4
5599.620	6, u	5713.799	1, u	5833.808	1, u
5605.214	0	5718.038	0	5871.947	1
5607.898	3	5726.875	1, u	5899.128	1
5608.541	4	5727.466	3	5907.478	1
5626.254	2	5730.600	2	5918.698	1
5632.954	2	5742.985	0	5941.743	1
5634.847	2	5755.894	0	5952.791	0
5651.466	1, u	5792.824	4	5983.830	4
5659.791	4	5795.936	2		

V. OSMIUM.

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2325.636	0	2371.270	1	2408.764	2
2327.081	0	2376.398	0	2409.010	1
2329.356	0	2377.128	2	2409.476	0
2332.288	1	2377.704	0	2410.282	0
2334.640	1	2378.842	0	2411.536	1
2336.876	1	2379.482	1	2411.992	0
2338.723	1	2379.730	0	2414.042	0
2340.732	0	2379.931	0	2414.198	0
2342.043	0	2382.595	0	2414.639	1
2343.831	1	2384.715	0	2415.436	0
2345.855	0	2387.378	2	2418.081	1
2347.480	0	2391.248	0	2418.457	0
2350.323	0	2393.986	0	2418.618	1
2351.678	0	2394.379	0	2420.137	0
2351.826	0	2395.969	0	2421.268	0
2355.378	0	2396.855	0	2421.949	0
2356.999	0	2397.730	0	2422.106	0
2357.344	0	2398.300	0	2423.158	2
2362.498	0	2401.219	2	2424.102	0
2362.855	2	2402.328	0	2424.655	1
2363.128	0	2402.620	0	2424.820	0
2363.421	1	2403.944	1	2426.297	0
2367.434	2	2405.176	0	2426.907	0
2369.346	1	2405.531	0	2427.280	0
2370.796	1	2406.053	0	2427.386	0

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2427.997	0	2491.106	2	2547.289	0
2429.025	0	2491.789	2	2548.196	2
2429.801	0	2492.477	2	2548.930	1
2431.299	1	2493.710	0	2550.873	0
2431.699	1	2493.935	0	2554.558	2
2434.605	0	2496.425	1	2555.205	1
2434.731	0	2498.512	1, u	2555.378	1
2437.798	0	2500.821	1	2555.902	1
2440.913	0	2501.016	0	2556.179	0
2442.104	0	2501.963	0	2557.868	0
2445.980	0	2502.382	2	2558.191	1
2446.125	1	2503.766	2	2560.308	0
2449.987	0	2504.486	2	2560.578	0
2450.581	0	2504.603	0	2560.831	0
2450.833	1	2506.481	0	2562.771	1
2451.290	0	2506.767	0	2563.257	2
2452.869	0	2507.282	0	2564.287	1
2453.392	0	2508.707	1	2564.469	0
2453.989	0	2509.809	0	2565.261	2
2454.278	0	2510.024	2	2565.816	0
2455.002	1	2510.591	0	2566.595	3
2455.422	0	2512.970	2	2567.335	0
2455.716	0	2513.340	2	2568.937	2
2456.555	1	2515 140	2	2570.855	0
2457.273	0	2518.006	2	2571.244	0
2457.804	0	2518.533	2	2571.611	0
2459.940	0	2519.886	1	2571.878	2
2461.508	3	2520.156	0	2572.572	1
2464.577	1	2524.879	0	2573.198	0
2466.535	0	2526.833	0	2573.601	0
2467.420	0	2527.174	0	2574.852	1
2468.209	0	2527.335	0	2577.141	0
2470.925	0	2527.832	1	2578.284	1
2472.378	1	2529.047	0	2578.430	2
2473.756	0	2532.083	1	2579.839	0
2475.064	0	2532.732	0	2580.120	2
2475.769	0	2534.270	1	2581.154	2
2476.179	0	2535.484	0	2582.027	4
2476.923	2	2536.184	0	2586.995	0
2477.100	0	2538.087	4	2587.575	1
2480.825	0	2538.174	1	2588.517	0
2481.892	1	2538.500	0	2589.495	0
2482.524	2	2539.751	0	2589.595	0
2485.424	0	2540.230	2	2590.859	4
2486.326	3	2540.835	2	2592.082	2
2488.415	1	2541.747	0	2594.000	0
2488.640	4	2542.592	4	2594.238	2
2488.890	0	2543.892	0	2596.101	2
2489.113	0	2544.067	4	2596.474	0
2489.370	0	2546.261	2	2596.783	2

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2597.092	0	2650.754	0	2696.709	0
2597.319	1	2651.562	0	2697.338	2
2597.664	0	2652.369	0	2698.321	0
2597.990	0	2653.068	2	2699.688	4
2600.008	1	2653.388	1	2700.840	2
2600.560	1	2653.860	2	2703.203	0
2600.855	0	2655.297	0	2704.551	2
2602.444	1	2655.879	1	2704.695	0
2603.323	0	2656.774	2	2705.547	0
2603.554	0	2657.203	0	2706.804	2
2604.701	2	2658.682	4	2707.519	2
2605.051	0	2659.924	2	2708.276	2
2608.342	0	2661.011	1	2709.953	2
2609.303	2	2662.069	2	2712.848	0
2609.669	2	2662.653	2	2713.300	0
2610.881	2	2663.314	2	2714.744	3
2611.410	2	2663.950	0	2714.997	0
2612.732	2	2664.390	0	2715.471	2
2613.167	4	2664.879	4	2715.726	2
2614.158	0	2665.370	0	2717.162	0
2615.122	0	2666.079	2	2717.488	0
2617.062	0	2666.295	2	2717.839	0
2617.895	0	2667.593	0	2718.796	1
2618.435	0	2669.158	0	2720.130	4
2618.923	0	2669.606	2	2720.578	1
2620.035	4	2670.640	0	2721.959	4
2620.723	2	2672.145	0	2722.700	0
2621.473	0	2674.654	2	2722.867	0
2621.912	2	2674.793	0	2727.357	0
2623.711	0	2674.969	2	2728.364	2
2624.677	0	2677.473	0	2729.093	0
2625.436	0	2678.870	0	2730.782	4
2628.377	2	2679.457	0	2731.467	1
2632.994	1	2679.825	1	2731.931	0
2634.375	2	2680.806	0	2732.905	4
2634.547	1	2682.279	2	2735.848	0
2637.223	4	2683.974	0	2736.479	1
2638.081	0	2684.497	2	2738.427	0
2638.428	0	2685.973	0	2738.636	2
2639.533	0	2686.624	0	2740.414	2
2640.079	0	2686.777	0	2740.701	2
2640.625	0	2687.277	0	2740.862	2
2641.271	1	2688.174	2	2742.801	0
2641.700	2	2689.447	2	2744.981	0
2643.132	1	2689.904	4	2745.632	1
2643.727	2	2691.483	0	2748.003	2
2644.211	4	2692.021	0	2748.964	2
2645.207	0	2692.790	2	2750.970	0
2647.817	2	2694.615	2	2751.246	2
2649.428	2	2694.854	0	2751.875	0

V. OSMIUM — *continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2753.792	2	2796.833	2	2846.507	2
2754.780	0	2799.692	1	2846.707	2
2755.680	0	2802.039	1	2847.408	0
2756.095	0	2804.055	0	2848.360	2
2757.902	2	2804.185	2	2849.175	2
2758.775	0	2805.576	0	2849.427	0
2758.923	2	2807.025	5	2850.877	4
2760.168	0	2807.600	0	2853.441	0
2761.184	2	2807.910	0	2853.971	0
2761.530	2	2808.357	0	2855.455	1
2762.745	0	2809.045	4	2857.117	0
2763.371	2	2809.815	0	2857.659	2
2764.032	2	2810.468	0	2858.210	0
2764.637	0	2810.680	0	2858.733	0
2765.143	2	2811.683	2	2860.184	2
2765.541	1	2813.130	0	2861.075	4
2766.650	0	2813.904	2	2861.895	0
2767.236	1	2814.318	3	2864.366	2
2768.369	0	2814.602	0	2865.131	0
2769.385	3	2814.962	2	2865.802	2
2769.975	1	2815.380	1	2865.892	0
2770.213	1	2815.895	2	2867.216	1
2770.825	4	2818.897	0	2872.529	3
2771.150	1	2819.349	1	2873.126	0
2771.869	0	2819.601	0	2873.534	3
2773.176	2	2820.298	2	2874.700	1
2773.592	0	2820.682	2	2875.083	4
2774.125	2	2821.367	2	2875.930	0
2774.257	0	2823.687	0	2876.602	0
2774.488	2	2824.051	0	2877.464	3
2775.004	2	2824.283	2	2878.524	3
2777.011	2	2824.918	0	2879.095	0
2779.197	1	2825.013	1	2879.956	0
2779.584	0	2825.437	0	2880.327	2
2780.269	0	2827.038	0	2880.477	0
2780.970	0	2827.670	0	2884.064	1
2781.972	1	2829.138	0	2884.537	2
2782.658	4	2829.390	2	2884.967	0
2785.147	2	2829.468	1	2885.295	0
2786.061	1	2831.693	2	2886.182	1
2786.414	4	2832.345	2	2886.368	0
2786.904	2	2837.542	2	2886.622	2
2787.153	1	2838.283	3	2889.280	1
2789.620	0	2838.751	5	2889.654	0
2791.007	2	2839.792	0	2890.970	2
2792.844	0	2840.557	2	2891.961	1
2794.091	2	2841.711	4	2892.466	1
2794.309	2	2844.501	4	2893.014	0
2795.275	1	2844.802	2	2896.183	3
2796.221	0	2845.067	0	2898.023	0

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2899.372	0	2937.111	0	2979.555	2
2901.308	0	2938.491	0	2979.802	0
2901.455	2	2938.590	0	2980.453	0
2903.193	2	2939.519	0	2982.252	2
2903.354	2	2940.208	0	2982.680	2
2905.862	2	2940.694	0	2983.032	3
2906.103	2	2940.873	0	2984.419	1
2906.909	0	2941.985	0	2984.751	0
2908.150	2	2942.267	1	2985.084	0
2908.468	0	2942.348	2	2985.752	2
2909.185	6	2942.692	0	2988.396	2
2909.797	2	2942.981	2	2989.253	2
2910.801	1	2943.291	2	2989.655	2
2911.269	0	2943.756	1	2989.963	0
2911.466	2	2945.437	0	2990.763	1
2911.695	0	2946.705	0	2992.240	3
2911.939	0	2947.277	0	2993.698	2
2912.470	2	2948.328	4	2994.908	0
2913.969	2	2949.635	3	2995.298	0
2914.341	1	2949.930	1	2995.762	2
2914.841	2	2950.986	1	2996.385	0
2915.382	0	2951.357	1	2997.777	3
2915.586	0	2952.412	2	3000.234	1
2916.193	0	2955.128	1	3003.605	2
2917.383	4	2956.629	2	3004.872	0
2917.946	3	2957.214	2	3005.064	0
2919.053	0	2957.774	0	3005.878	0
2919.380	0	2958.467	1	3008.022	2
2919.935	4	2961.140	4	3012.902	1
2920.204	1	2961.526	0	3013.194	4
2920.974	0	2962.272	4	3014.068	2
2921.193	2	2962.465	2	3015.158	0
2922.818	0	2962.819	0	3015.772	2
2923.109	0	2963.005	1	3017.380	3
2923.298	2	2963.178	0	3018.169	4
2924.617	2	2964.190	4	3018.440	0
2925.414	2	2964.890	0	3018.744	0
2925.708	3	2965.215	1	3019.498	3
2927.370	0	2966.217	0	3020.782	3
2929.646	2	2966.428	0	3021.226	0
2930.334	2	2966.685	0	3022.382	0
2930.704	2	2967.860	0	3024.434	0
2931.416	4	2969.938	0	3027.659	1
2931.879	0	2970.825	0	3027.790	0
2932.585	2	2971.098	3	3028.032	2
2934.111	3	2975.461	2	3029.496	2
2934.420	0	2976.470	0	3030.817	4
2934.779	3	2977.757	3	3031.122	2
2935.083	0	2978.338	2	3031.418	2
2936.817	2	2978.645	2	3031.828	1

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3032.924	2	3074.192	4	3116.593	2
3033.331	2	3074.771	0	3117.215	0
3033.843	0	3075.074	4	3118.014	1
3036.668	2	3076.845	1	3118.242	2
3040.184	1	3077.167	3	3118.450	2
3041.021	5	3077.557	2	3119.196	0
3042.860	2	3077.834	4	3120.016	2
3043.622	2	3078.227	2	3120.777	0
3043.793	2	3078.496	2	3121.307	0
3044.040	1	3080.614	0	3121.592	0
3044.191	2	3080.907	0	3124.142	1
3044.525	2	3081.313	0	3125.643	0
3045.031	2	3083.565	0	3127.620	0
3045.430	2	3084.715	2	3128.677	1
3045.898	2	3085.004	2	3129.348	2
3046.200	0	3085.982	0	3130.125	2
3047.574	1	3086.394	2	3131.021	0
3049.172	2	3087.125	0	3131.227	4
3049.580	3	3087.868	2	3131.600	1
3050.517	3	3088.385	2	3131.995	0
3051.280	2	3088.545	0	3133.953	1
3052.540	2	3090.205	2	3134.805	0
3053.004	0	3090.416	2	3135.126	0
3053.743	0	3090.613	2	3136.334	0
3054.091	2	3091.368	2	3136.785	0
3054.620	1	3092.613	0	3137.421	0
3054.780	0	3093.704	3	3137.636	2
3055.086	2	3194.192	1	3138.157	1
3055.326	2	3102.503	1	3139.745	0
3055.726	0	3102.835	2	3140.431	2
3056.315	0	3103.412	0	3141.056	2
3057.014	1	3105.098	2	3143.169	2
3058.782	6	3106.114	3	3144.471	2, d?
3060.248	0	3106.762	0	3146.074	2
3060.412	3	3107.119	0	3146.843	0
3061.814	1	3107.495	2	3147.601	0
3062.039	0	3107.989	2	3149.365	0
3062.297	4	3108.098	2	3149.927	1
3062.584	1	3108.846	0	3150.260	0
3062.803	2	3109.102	3	3150.730	0, U
3063.480	1	3109.504	4	3151.005	0
3065.391	0	3109.800	2	3152.181	3
3065.783	0	3110.538	1	3152.806	4
3066.225	2	3110.743	2	3153.727	4
3066.715	1	3111.196	3	3154.666	0
3066.945	2	3112.630	0	3155.450	1
3070.049	3	3113.405	0	3156.365	6
3070.374	1	3114.932	2	3156.878	3
3071.974	1	3115.150	1	3157.102	0
3072.681	0	3115.838	0	3157.342	1

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3159.477	0	3220.318	1	3275.320	4
3160.397	0	3220.408	0	3276.533	0
3160.540	0	3220.895	4	3278.086	4
3161.547	1	3221.444	0	3279.590	1
3161.837	1	3223.987	1	3281.028	2
3164.550	0	3226.579	0	3281.778	0
3164.718	2	3227.409	2	3284.680	0
3165.772	2	3229.336	0	3288.616	0
3166.611	4	3230.525	0	3288.960	2
3168.390	2	3231.410	0	3289.387	4
3171.249	0	3231.543	2	3291.259	1
3173.306	2	3232.072	2	3298.374	0
3173.609	0	3232.196	4	3301.692	7
3174.037	4	3232.672	1	3301.990	1
3174.284	1	3234.318	2	3304.980	0
3175.781	0	3234.651	0	3305.501	2
3177.522	1	3234.858	0	3306.352	2
3178.184	4	3238.304	1	3311.035	4
3178.357	2	3238.751	4	3312.178	0
3180.237	1	3239.398	0	3315.555	2
3181.907	1	3241.159	3	3315.816	2
3183.341	0	3241.642	2	3316.822	2
3183.661	1	3241.933	0	3317.420	0
3183.905	0	3242.108	1	3317.998	0
3184.458	0	3243.700	0	3318.284	0
3185.304	0	3248.106	0	3318.724	0
3185.439	3	3250.695	0	3322.175	0
3186.516	2	3250.974	0	3322.734	1
3186.643	2	3255.038	3	3324.486	4
3187.096	4	3255.139	0	3324.876	0
3187.443	2	3255.414	0	3325.518	2
3189.566	3	3257.051	4	3325.644	0
3193.986	2	3259.530	0	3327.562	4
3194.350	4	3260.420	3	3329.252	0
3194.805	3	3260.683	1	3333.986	0
3195.494	2	3262.428	6	3334.295	2
3196.082	1	3262.880	4	3336.282	4
3196.152	0	3264.820	2	3339.601	0
3197.310	0	3266.565	2	3340.851	0
3202.956	1	3266.890	0	3342.018	2
3204.155	2	3267.338	2	3348.791	2
3204.646	0	3268.080	6	3351.853	2
3205.909	0	3269.340	4	3354.042	1
3212.240	2	3270.025	0	3358.095	4
3212.840	2	3271.002	0	3359.876	1
3213.418	3	3271.320	0	3361.280	3
3216.340	0	3272.118	0	3361.905	0
3217.177	1	3272.301	3	3362.716	0
3218.153	0	3272.607	0	3364.250	1
3219.260	0	3273.513	1	3364.486	0

V. OSMIUM — *continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3368.617	2	3469.517	0	3965.106	1
3370.340	2	3477.798	0	3969.832	2
3370.725	4	3478.670	2	3975.596	3
3371.602	1	3482.269	2	3977.389	4
3372.929	0	3482.380	2	3979.524	0
3373.337	0	3487.387	2	3988.340	2
3375.262	0	3487.610	2	3988.785	0
3377.088	2	3488.915	2	3995.103	0
3380.674	0	3490.464	2	3996.979	0
3381.814	2	3498.686	2	3999.110	0
3383.042	2	3501.314	2	4003.652	2
3384.732	2	3504.811	4	4004.184	2
3386.077	2	3513.145	1	4015.203	0
3386.277	3	3513.791	2	4018.425	0
3387.970	4	3528.743	3	4035.249	0
3388.794	1	3598.260	2	4036.640	0
3391.401	1	3601.984	0	4038.009	0
3395.862	2	3604.624	2	4038.813	0
3396.973	2	3616.726	2	4042.081	2
3397.910	0	3630.099	0	4048.216	0
3398.713	0	3640.487	4	4051.584	0
3400.264	0	3648.962	1	4053.417	2
3401.315	2	3653.873	0	4055.647	1
3402.002	4	3654.631	2	4055.859	0
3402.643	3	3657.048	2	4066.460	0
3402.855	0	3671.040	3	4066.862	3
3406.423	2	3675.599	1	4071.020	0
3406.816	2	3681.705	2	4071.169	0
3408.906	2	3689.191	4	4073.768	2
3412.908	0	3691.750	0	4074.829	0
3412.946	0	3700.688	1	4088.598	0
3414.390	1	3703.391	2	4091.980	2
3421.558	0	3746.612	0	4097.087	1
3421.837	2	3895.331	0	4098.233	0
3422.800	1	3900.541	2	4100.436	0
3427.590	0	3901.851	2	4112.177	2
3427.816	5	3915.543	0	4124.760	0
3434.023	4	3925.253	1	4129.114	0
3437.150	2	3926.923	1	4135.955	4
3437.642	0	3928.557	0	4138.021	1
3438.792	0	3928.691	0	4152.448	0
3439.639	1	3930.148	0	4172.708	1
3444.616	2	3931.660	2	4173.391	2
3445.695	3	3938.739	2	4175.783	1
3449.352	4	3939.704	1	4190.059	2
3455.172	2	3949.925	0	4201.541	0
3459.163	2	3952.904	0	4212.028	3
3462.335	1	3960.656	2	4219.005	0
3465.029	0	3961.159	2	4229.531	0
3465.585	2	3963.774	4	4233.630	1

V. OSMIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
4241.682	0	4377.070	1	4525.035	1
4251.321	0	4385.068	0	4529.848	1
4252.718	0	4386.485	1	4540.093	2
4261.011	4	4390.406	0	4548.836	1
4264.893	2	4391.251	2	4550.584	4
4269.526	0	4395.040	4	4551.461	3
4269.767	2	4397.424	3	4595.206	3
4270.952	1	4400.751	1	4597.321	2
4273.984	0	4402.901	3	4616.948	4
4275.074	0	4404.375	1	4632.000	4
4277.315	1	4410.899	1	4634.930	1
4281.535	0	4411.298	1	4642.010	0
4286.056	2	4420.639	5	4663.977	4
4294.105	2	4428.059	1	4692.220	2
4296.382	2	4432.584	2	4738.215	1
4297.556	0	4436.490	3	4738.508	2
4299.870	0	4437.258	1	4744.050	2
4309.041	1	4439.808	2	4755.332	1
4311.561	4	4445.582	1	4763.263	0
4317.754	0	4445.854	0	4794.177	5
4319.513	0	4447.535	3	4816.105	2
4326.413	2	4459 646	0	4865.759	2
4328.838	3	4459.790	0	4899.386	0
4338.913	3	4462.473	1	4912.771	1
4342.681	1	4466.134	1	4937.522	0
4351.695	2	4479.974	2	5031.988	1
4354.631	1	4484.935	2	5103.670	2
4358.157	1	4488.771	1	5149.895	2
4358.318	1	4503.474	0	5202.789	3
4361.126	0	4507.590	0	5523.786	2
4365.835	3	4514.445	0	5728.735	2
4370.826	3	4519.050	0		

VI. IRIDIUM.

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2321.481	0	2395.974	0	2456.882	0
2321.622	0	2398.824	0	2457.123	2
2324.006	0	2401.866	2	2457.312	2
2324.754	0	2402.379	1	2462.454	0
2325.029	1	2403.113	0	2463.118	1
2328.046	0	2405.955	0	2464.462	0
2328.324	0	2406.115	0	2467.382	3
2328.598	0	2409.465	1	2468.263	0
2328.790	0	2410.264	2	2468.705	1
2329.469	0	2410.818	1	2469.594	0
2333.372	2	2414.473	0	2469.848	0
2333.917	2	2415.950	2	2470.143	0
2334.406	0	2416.334	0	2470.607	0
2334.575	2	2416.672	0	2472.709	0
2337.628	0	2418.190	2	2474.170	1
2342.573	0	2418.657	0	2475.209	4
2342.763	1	2420.698	1	2478.190	1
2343.062	0	2421.306	0	2479.255	0
2343.255	2	2422.286	0	2480.685	0
2343.684	2	2424.406	0	2481.262	3
2347.329	1	2424.741	0	2482.383	0
2349.400	0	2424.971	1	2486.463	0
2349.790	0	2425.069	2	2486.826	0
2350.136	0	2425.744	2	2488.325	0, u
2351.492	1	2426.622	1	2489.293	0
2352.705	0	2426.875	0	2491.778	0
2355.082	2	2427.189	0	2492.406	0
2356.122	0	2427.694	2	2493.163	2
2356.388	0	2427.878	0	2495.680	1
2356.674	2	2429.830	0	2495.951	0
2357.623	0	2431.331	2	2496.360	2
2358.245	1	2432.021	2	2500.357	0
2359.668	0	2432.439	1	2502.710	2
2360.790	2	2432.667	0	2503.068	4
2363.134	4	2433.433	0	2504.446	2
2365.849	1	2434.107	0	2505.308	0
2367.469	0	2436.513	0	2505.814	1
2368.120	4	2445.184	0	2507.712	2
2368.486	0	2445.436	2	2508.434	0
2370.462	2	2446.926	0	2509.798	0
2372.856	4	2447.583	0	2512.016	1
2375.195	2	2447.850	2	2512.191	0
2381.714	2	2448.316	1	2512.665	2
2383.270	1	2449.112	1	2513.799	2
2383.840	0	2449.916	0	2515.448	0
2386.665	1	2452.893	3	2521.175	0
2386.981	2	2454.212	1	2523.290	0
2390.706	2	2454.945	0	2524.953	0
2391.282	3	2455.691	2	2526.856	0
2394.404	0	2455.949	2	2527.868	0

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2528.011	0	2589.057	0	2653.124	3
2529.559	1	2589.231	0	2653.853	2
2529.870	0	2589.470	0	2654.033	2
2530.200	0	2590.296	0	2654.670	0
2530.498	0	2591.129	1	2656.898	3
2530.786	0	2591.927	1	2657.587	0
2532.290	0	2592.146	4	2657.799	2
2534.103	0	2593.224	1	2657.993	0
2536.760	0	2595.188	0	2660.040	0
2537.309	2	2595.914	2	2660.163	0
2537.770	1	2599.129	2	2661.080	0
2538.548	0	2599.224	0	2662.080	6
2538.949	0	2602.122	2	2662.706	4
2540.483	1	2604.645	2	2663.400	2
2541.556	1	2606.081	0	2664.871	5
2542.097	2	2606.668	0	2665.144	0
2544.059	5, u	2607.608	2	2667.540	2
2545.620	1	2608.314	4	2668.362	0
2545.868	0	2609.996	0	2669.070	2
2547.278	1	2610.198	0	2670.006	3
2550.987	0	2611.384	3	2671.930	4
2551.475	2	2612.136	0	2672.888	0
2554.480	2	2612.344	1	2673.694	4
2555.425	2	2614.287	1	2675.376	0
2555.955	1	2615.064	2	2676.911	2
2556.860	1	2616.090	2	2677.899	0
2557.285	0	2617.177	0	2679.506	0
2558.821	0	2617.514	0	2681.184	2
2559.643	0	2617.872	2	2682.536	2
2562.999	0	2618.352	0	2683.387	0
2563.365	1	2619.967	2	2688.381	0
2564.253	4	2620.102	0	2689.769	0
2564.922	0	2621.610	0	2691.154	2
2566.442	0	2622.203	0	2691.998	0
2568.407	0	2623.736	1	2692.267	0
2569.962	2	2625.396	2	2692.429	4
2572.156	2	2626.844	2	2692.964	2
2572.459	2	2628.271	0	2693.571	2
2572.784	3	2629.498	2	2694.320	6
2573.338	0	2634.340	3	2695.550	0
2577.622	0	2634.513	0	2696.010	1
2578.794	2	2635.353	2	2698.688	2
2579.008	2	2636.967	0	2701.200	2
2579.573	2	2637.407	0	2704.117	3
2579.860	0	2639.073	2	2704.722	0
2581.019	0	2639.510	2	2705.213	0
2581.523	0	2640.462	2	2705.296	0
2583.261	1	2644.279	2	2705.453	0
2584.867	0	2646.334	2	2705.632	1
2586.146	0	2650.584	0	2706.985	0

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2707.265	0	2767.764	2	2824.546	6
2708.752	0	2771.711	3	2826.316	0
2710.177	2	2772.547	4	2827.259	2
2711.402	0	2774.685	2	2829.720	1
2712.817	4	2775.073	2	2830.264	3
2713.195	1	2775.646	4	2830.601	2
2714.643	1	2777.149	0	2830.964	0
2716.612	0	2777.536	2	2831.455	2
2717.730	0	2777.645	0	2831.912	1
2719.906	0	2779.752	1	2832.874	2
2720.534	2	2780.507	0	2833.337	4
2721.443	0	2781.047	2	2833.777	0
2723.248	0	2781.401	4	2835.408	0
2723.849	2	2782.342	0	2835.762	2
2724.884	0	2782.885	0	2836.197	1
2726.566	1	2783.492	0	2836.506	4
2728.224	0	2783.797	0	2837.421	2
2728.494	1	2785.319	4	2839.287	6
2729.638	2	2787.099	1	2840.332	4
2730.500	0	2787.687	0	2841.798	2
2731.954	0	2789.066	0	2842.390	2
2732.752	2	2790.795	0	2845.009	0
2734.596	0	2793.907	0	2845.245	1
2735.165	1	2794.189	2	2846.753	0
2736.509	0	2796.558	2	2848.557	0
2738.875	0	2797.456	4	2849.557	0
2739.413	2	2798.283	4	2849.848	6
2740.085	2	2799.522	0	2850.906	0
2740.166	0	2799.835	3	2851.161	0
2740.267	2	2800.755	1	2851.518	1
2740.432	1	2800.923	4	2851.648	2
2743.477	0	2804.300	0	2852.605	0
2743.769	0	2806.479	2	2853.416	2
2744.091	4	2806.772	0	2854.722	0
2747.383	0	2807.754	2	2855.931	2
2747.602	2	2808.249	0	2856.048	2
2748.395	0	2810.657	2	2857.058	2
2749.075	0	2812.896	3	2859.138	0
2753.954	0	2814.532	2	2860.126	0
2756.206	1	2814.966	2	2860.767	3
2758.325	2	2815.744	0	2862.455	1
2759.100	2	2816.409	0	2863.955	4
2759.405	2	2817.039	2	2866.798	4
2760.009	2	2817.284	0	2869.815	3
2760.207	0	2819.848	0	2870.304	0
2760.474	0	2820.614	0	2870.698	0
2761.227	0	2820.738	2	2872.227	0
2761.700	0	2823.280	5	2873.929	0
2763.287	0	2823.831	0	2875.721	4
2767.423	3	2824.228	1	2876.096	4

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
2877.108	0	2931.821	0	2982.962	0
2877.781	4	2933.252	2	2985.921	4
2878.632	2	2934.748	4	2988.335	0
2879.515	4	2935.305	0	2990.746	3
2879.878	0	2935.427	0	2991.520	1
2880.174	0	2936.814	3	2993.184	2
2880.324	2	2937.371	0	2993.751	0
2881.270	2	2937.656	0	2996.202	4
2882.742	4	2938.097	0	2996.785	0
2882.970	0	2938.606	3	2997.314	3
2883.549	2	2938.877	0	2999.155	0
28 5.615	0	2939.390	0	3000.149	2
2887.240	2	2940.548	0	3001.383	0
2889.688	1	2940.669	2	3002.086	1
2890.634	0	2941.197	2	3002.375	4
2892.371	1	2943.287	5	3003.761	4
2893.785	0	2947.093	4	3004.429	0
2894.388	0	2949.882	3	3005.338	3
2895.705	0	2950.606	1	3007.745	0
2897.070	2	2950.883	2	3007.838	0
2897.260	4	2951.266	2	3008.753	1
2897.783	0	2951.363	2	3010.020	3
2898.455	2	2952.686	0	3011.812	3
2899.055	0	2953.205	0	3012.695	2
2899.733	3	2954.909	1	3012.984	1
2900.165	0	2956.301	0	3014.585	1
2900.492	2	2956.699	0	3014.854	1
2902.430	0	2959.049	0	3016.550	3
2903.852	0	2959.573	0	3017.450	4
2903.995	0	2961.009	2	3018.151	2
2904.913	4	2961.595	2	3019.350	4
2905.744	2	2962.580	1	3020.125	4
2907.353	4	2963.111	4	3022.536	3
2909.669	4	2965.095	0	3022.807	3
2909.912	0	2965.329	3	3024.410	2
2913.592	0	2966.245	2	3026.489	1
2915.625	0	2967.360	0	3029.487	4
2915.793	0	2968.334	2	3030.365	1
2916.479	4	2971.205	2	3030.568	0
2917.347	0	2972.119	0	3032.528	3
2917.885	2	2972.646	0	3033.744	3
2918.683	3	2974.220	1	3034.675	2
2919.299	0	2974.659	1	3036.361	0
2921.237	0	2975.062	4	3037.861	3
2924.912	7	2976.857	0	3039.378	5
2926.212	0	2978.056	2	3040.580	4
2927.129	2	2980.375	0	3041.056	1
2927.833	0	2980.578	0	3041.979	1
2930.298	2	2980.776	4	3042.429	0
2930.743	3	2981.042	2	3042.760	2

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3043.671	0	3088.163	4	3154.679	2
3044.255	0	3089.660	0	3154.874	3
3045.768	0	3090.277	2	3156.274	2
3047.277	4	3090.871	0	3157.614	2
3047.905	1	3091.254	0	3157.836	0
3048.783	1	3094.144	2	3159.280	5, d?
3049.559	4	3094.326	1	3159.644	2
3050.134	1	3097.147	0	3159.992	1
3051.243	3	3097.482	0	3161.477	2
3052.288	3, d?	3097.931	2	3161.948	2
3053.709	3	3098.555	0	3162.445	0
3054.351	0	3099.055	2	3162.871	0
3054.570	1	3100.586	2	3162.953	0
3056.770	0	3101.288	2	3163.972	1
3057.398	2	3103.667	1	3164.376	0
3057.590	2	3103.875	2	3165.323	1
3058.087	0	3104.301	0	3165.833	1
3058.438	0	3106.072	0	3166.886	2
3059.858	1	3108.670	2	3167.328	3
3060.114	1	3112.475	2	3167.792	0
3060.460	0	3113.259	1	3168.297	3
3060.950	2	3113.908	1	3168.404	1
3061.515	4	3114.170	4	3168.673	0
3064.216	0	3114.669	4	3169.010	5
3064.622	4	3117.457	0	3171.812	2
3064.904	3	3117.645	2	3172.915	3
3065.292	0	3117.968	0	3173.222	0
3065.944	0	3118.967	1	3173.466	1
3066.167	0	3119.422	0	3176.106	0
3066.766	0	3120.885	5	3177.325	0
3068.507	1	3121.894	4	3177.712	4
3069.005	4	3122.509	4	3178.811	2
3069.220	2	3123.334	2	3179.328	3
3069.825	2	3124.024	0	3180.487	2
3072.078	0	3124.203	2	3182.514	0
3072.904	0	3128.510	4	3182.924	1
3073.390	2	3133.210	2	3186.030	0
3073.800	0	3133.432	5, u R	3186.184	0
3074.864	2	3135.358	0	3186.667	1
3075.577	0	3136.418	0	3187.267	0
3076.800	4	3139.704	2	3188.487	0
3077.996	1, u	3141.947	1	3188.702	1
3078.793	2	3142.371	1	3189.486	2
3079.892	0	3142.994	0	3193.240	1
3081.709	1	3143.668	0	3193.345	2
3082.828	0	3147.860	2	3195.882	0
3083.085	1	3148.346	0	3198.226	2
3083.343	4	3150.128	0	3199.058	5
3085.088	1	3150.727	2	3200.166	2
3086.564	4	3151.748	2	3201.027	2

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3202.023	0	3245.510	0	3303.771	3
3202.250	0	3246.431	2	3304.460	0
3204.230	0	3246.951	0	3305.057	3
3204.587	2	3247.417	1	3305.787	1
3205.227	4	3249.638	2	3305.980	2
3205.837	0	3249.866	3	3307.774	2
3208.287	2	3253.497	1	3308.581	0
3209.050	0	3254.542	4	3308.939	0
3210.131	2	3256.194	2	3309.535	2
3212.240	3	3256.346	1	3310.052	0
3212.350	2	3257.916	2	3310.674	4
3212.629	0	3262.147	4	3311.161	2
3213.681	4	3262.852	2	3311.365	0
3216.431	0	3263.062	2	3312.268	4
3216.905	1	3263.436	2	3313.472	0
3217.301	0	3265.399	0	3316.129	0
3217.700	0, u	3266.580	6	3316.534	0, u
3218.593	4	3267.236	1	3316.771	4
3220.924	6, u	3268.663	0	3317.457	2
3221.415	3	3269.835	0	3317.664	0
3222.600	1	3271.372	4	3318.596	2
3222.854	0	3271.936	4	3318.812	0
3223.138	0	3272.772	0	3319.231	2
3223.645	2	3274.686	2	3319.680	0
3224.016	2	3275.167	2	3320.504	1
3224.637	0	3275.452	1	3321.901	0
3226.840	3	3275.735	2	3322.750	4
3227.675	0	3276.291	1	3323.011	4
3228.672	0	3277.422	4	3326.056	0
3229.412	5, u	3280.011	0	3326.245	2
3230.903	5	3280.705	1	3326.687	0
3232.145	5, u	3282.024	0	3327.039	2
3232.342	1	3282.458	2	3327.688	0
3232.618	0	3284.456	1	3330.968	0
3235.370	0	3284.695	1	3333.600	0
3235.537	0	3285.721	0	3334.318	4
3237.115	0	3287.198	4	3335.185	0
3238.003	0	3287.726	4	3336.195	2
3238.414	1	3290.640	0	3337.637	0
3238.675	0	3291.010	0	3337.985	1
3240.351	4	3291.187	0	3338.535	4
3240.688	2	3294.150	0	3339.028	0
3241.395	0	3294.251	0	3339.532	3
3241.640	4	3295.220	2	3340.485	2
3242.132	1	3297.655	2	3342.930	0
3242.462	2	3300.732	0	3343.182	0
3242.734	2	3301.502	0	3343.745	0
3243.568	0	3301.735	0	3344.360	2
3244.887	0	3301.900	1	3346.609	1
3245.022	2	3303.236	2	3347.695	2

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3348.015	1	3420.111	0	3557.325	3
3352.987	0	3420.646	2	3559.160	3
3353.696	1	3420.895	0	3568.156	1
3355.739	0	3421.923	2	3573.888	3
3355.942	2	3424.854	4	3594.308	2
3356.342	1	3425.526	1	3594.557	4
3356.697	0	3429.026	2	3596.356	0
3359.262	0	3429.748	0	3598.936	4
3360.038	6	3430.197	2	3601.568	4
3360.950	7	3430.941	0	3605.958	2
3364.380	2	3431.476	1	3609.933	4
3365.273	0	3432.930	0	3617.378	4
3365.678	0	3433.475	2	3619.326	2
3367.063	2	3434.915	2	3623.976	1
3367.210	2	3435.200	0	3625.872	3
3368.640	6	3435.554	0	3626.460	4
3370.785	2	3437.189	6	3628.843	5
3371.594	4	3437.670	4	3629.317	2
3372.958	1	3438.244	2	3629.911	3
3374.597	2	3445.682	0	3636.370	4
3374.942	0	3446.476	4	3641.037	1
3376.146	0	3446.793	2	3645.468	1
3377.288	0, u	3448.621	0	3647.857	1
3378.119	0, u	3449.133	6	3653.358	1
3378.550	0, u	3450.916	1	3657.774	0
3379.993	2	3455.949	2	3661.527	2
3381.151	3	3465.390	4	3661.867	5
3383.474	0	3468.749	2	3664.780	4
3383 917	0	3476.182	0	3675.160	4
3385.272	2	3476.611	3	3688.321	1
3385.752	2	3477.930	1	3689.476	0
3386.330	2	3481.254	1	3692.851	3
3386.417	0	3482.760	3	3696.308	2
3386.678	0	3484.256	2	3698.261	2
3388.023	1	3484.649	4	3701.107	2
3388.158	2	3485.660	3	3707.147	3
3389.473	1	3488.727	2	3712.630	3
3391.032	1	3492.217	0	3721.628	1
3395.129	3	3494.787	3	3722.904	3
3401.927	4	3496.580	1	3725.536	3
3402.182	2	3499.272	1	3731.504	4
3402.962	2	3503.088	2	3734.900	1
3409.931	2	3508.731	1	3738.682	2
3410.180	2	3510.793	2	3742.948	1
3411.730	2	3512.054	1	3747.352	4
3412.762	2	3512.356	2	3750.539	2
3415.408	3	3513.807	4	3768.817	2
3415.906	2	3516.110	2	3794.211	0
3418.533	0	3522.191	2	3799.047	2
3419.592	4	3552.223	2	3800.243	2

VI. IRIDIUM—*continued.*

Wave-length	Intensity and Character	Wave-length	Intensity and Character	Wave-length	Intensity and Character
3817.385	0	4172.736	1	4478.649	4
3889.715	0	4182.626	1	4491.523	2
3902.632	3	4200.031	2	4492.333	1
3902.807	2	4212.197	0	4495.525	3
3909.219	0	4212.383	2	4496.200	1
3915.055	2	4217.908	2	4533.003	2
3915.538	4	4218.243	0	4538.819	1
3923.634	2	4218.428	1	4545.837	4
3924.573	1	4220.950	2	4548.645	4
3931.903	0	4223.327	0	4550.941	2
3934.063	2, u	4230.486	0	4568.246	4
3935.005	4	4240.644	0	4570.183	2
3941.242	0	4241.198	0	4604.629	3
3944.534	1	4243.944	0	4614.342	0
3946.420	4	4257.528	2	4616.549	6
3948.459	1	4259.280	4	4640.231	2
3950.259	0	4261.408	2	4656.329	4
3952.099	2	4262.051	0	4669.130	2
3956.262	0	4265.450	2	4702.751	0
3962.926	2	4266.202	1	4709.034	2
3976.466	5	4266.532	0	4729.005	4
3978.240	0	4268.251	4	4732.014	1
3985.003	2	4269.101	0	4756.613	4
3987.963	2	4286.776	2	4758.107	2
3989.575	2	4300.802	1	4778.330	4
3992.277	6	4301.776	4	4795.827	3
3996.602	0	4305.359	0	4807.302	0
4005.164	1	4310.750	4	4809.636	2
4005.717	1	4311.669	5	4840.934	2
4020.194	5	4316.456	1	4845.539	0
4033.923	4	4330.060	0	4938.225	1
4040.224	4	4332.490	0	4939.311	0
4040.578	1	4351.462	1	4970.629	0
4048.782	0	4352.720	2	4999.898	2
4051.071	2	4362.289	1	5002.874	1
4051.538	0	4376.575	0	5009.323	0
4055.833	0	4377.175	3	5046.227	0
4056.620	2	4380.930	0, u	5050.001	0
4059.377	2	4392.758	3	5178.128	1
4070.067	4	4399.645	6	5239.091	1
4070.822	3	4403.952	4	5340.932	1
4072.532	2	4406.926	0	5357.081	0
4075.774	2	4411.344	2	5364.507	2
4080.737	2	4422.121	1	5449.716	4
4081.564	0	4425.936	0	5454.724	2
4082.542	1	4426.459	6	5469.648	1
4092.767	3	4449.540	0	5620.266	1
4115.957	4	4450.346	2	5625.772	3
4166.224	3	4452.987	1	5894.324	2

BONN, November 19, 1897.

Minor Contributions and Notes.

NOTES ON THE USE OF THE GRATING IN STELLAR SPECTROSCOPIC WORK.

THE results which have been obtained by Professor Poor in the direct use of the concave grating as an objective spectroscope in stellar spectroscopic work seem most promising. The writer (in common, no doubt, with many others) has long had in mind the utilization of gratings, both plane and concave, in this line of work. About two years ago (October, November 1895) I developed the general theory of the objective grating,[1] and indicated a number of methods of constructing, mounting, and using such gratings. At that time I made a number of laboratory experiments with the form of concave grating mounting now used by Professor Poor, and a little later, in conjunction with Professor Hale, made a practical test of a 12-inch wire grating, constructed under my direction in the Kenwood instrument shops, and attached to the Kenwood telescope. With this instrument the spectra of a number of stars were obtained, some as faint as the 3.6 magnitude. The details regarding some of the exposures are given in the following table. The plates used were ordinary Seed "26." In many cases, where the exposure was sufficiently long to show more than one order of spectra, the development was arrested before it was complete in order to avoid too great density in the spectra of the first order.

The results, therefore, were very satisfactory as regards the necessary times of exposure (which in many cases, *e. g.*, GG 10, 11, 17, 19, 20, 21, might have been made much shorter by making the spectra narrower). Considering the small photographic resolving power, which was between 500 and 800 units, or about the same as that of a flint prism of something less than one-fourth of an inch base, and the generally bad atmospheric conditions during the months in which the experiments were carried on (March, April), the *definition* in the best of the spectra obtained, and the resulting degree of *accuracy* with

[1] "The Modern Spectroscope. XV. Use of the Concave Grating as an Analyzing or Direct Comparison Spectroscope," this JOURNAL, January 1896, pp. 54-62. "The Modern Spectroscope. XIX. The Objective Spectroscope," *ibid.*, June 1896, pp. 75-78.

Plate number	Date	Star	Mag.[1]	Time exposure	Width of spectrum[2]	Remarks
GG	1896			min.	mm	
5	March 11	Procyon	+0.5	1.0	0.2±	1st order, overexposed
10	March 21	β Leonis	+2.2	20.0	0.6±	1st order, somewhat overexposed 2d order, distinct but underexposed 3d order, traces
11	March 23	Sirius	—1.4	3.3	2.5	1st order, overexposed 2d order, distinct but underexposed 3d order, traces
12	March 23	Sirius	—1.4	10.0	0.3±	1st order, much overexposed 2d order, fully exposed 3d order, distinct but underexposed
16	March 30	Procyon	+0.5	8.0	0.2±	1st order, much overexposed 2d order, fully exposed 3d order, distinct but underexposed
17	April 3	γ Leonis	+2.2	3.0	0.8	1st order, fully exposed 2d order, underexposed
18	April 3	ζ Leonis	+3.6	13.0	0.15±	1st order, much overexposed 2d order, nearly fully exposed 3d order, distinct but underexposed
19	April 4	β Leonis	+2.2	4.0	1.1	1st order, little overexposed 2d order, underexposed 3d order, traces
20	April 6	δ Leonis	+2.8	8.0	0.7±	1st order, overexposed 2d order, underexposed
21	April 6	δ Leonis(?)	+2.8	5.0	0.5±	1st order, fully exposed 2d order, distinct traces

which the *absolute* wave-lengths of the lines could be determined directly from the plates, were also most satisfactory.[3] The dismounting of the Kenwood telescope soon after this, temporarily put an end to these experiments. It was intended, as indicated in our paper,[4] to

[1] *H. P.*

[2] Owing to the chromatic aberration of the object-glass (the photographic objective was used) and the varying sensitiveness of the plates for different wave-lengths, the spectrum varies in width from point to point in any one order and is also different for different orders. The value given is the average width for that part of the spectrum for which the exposure is about normal.

[3] *Loc. cit.*, pp. 76, 77.

[4] *Loc. cit.*, p. 78.

undertake the construction of a larger wire grating for the 40-inch telescope, the one constructed for the 12-inch having (necessarily) too small a resolving power to be useful for anything more than a preliminary study of the method.

In comparing the efficiency of the concave and plane grating in stellar spectroscopic work, it may be noted first of all that the former has the same advantage over the latter, *when used as an objective spectroscope*, as when used in the laboratory; *i. e.*, it avoids all the losses due to the absorption, reflection, and diffusion of light by the additional lenses or mirrors necessary in the plane grating train; losses which become particularly serious in the case of large objectives when we are working with the ultra-violet or infra-red part of the spectrum. But although these advantages were fully recognized at the time the laboratory experiments already referred to[1] were made, it was feared that with the gratings of the linear and angular aperture then available, the time of exposure required to obtain good *stellar* spectra would be so long as to make the use of such gratings impracticable for any but the very brightest stars. Professor Poor's results with a comparatively small grating (ruled surface 1 by 2 inches, focal length about 40 inches) show, however, that the advantages attendant upon getting rid of the losses of light by the absorption and diffusion of the large telescope objective, are more considerable than was anticipated, and it now becomes of interest to determine as well as may be from his results, what may be expected from concave gratings of larger linear and angular apertures.

Let us assume, as a basis of comparison, a constant photographic purity of spectrum Q_0. From equation 26 (this JOURNAL, May 1896, p. 338) we have

$$Q = \frac{\lambda}{n e \beta} r \qquad (1)$$

where r is the theoretical resolving power of the spectroscope train, β the angular aperture of the camera, e the diameter of the silver grains in the plate, and n a constant which, in this case (where the slit-width is simply the angular magnitude of the star and may therefore be neglected), is about 4. We also have for the intensity of a continuous stellar spectrum formed by an objective spectroscope (this JOURNAL, June 1896, p. 58, equation 6),

[1] *Loc. cit.*, pp. 57, 58.

$$i' = \text{Const } A^2 \beta^2 . \frac{1}{r} \qquad (2)$$

where A is the diameter of the objective. For a rectangular aperture (such as we have in the case of a grating) of height (length of ruled lines) B and aperture (length of ruled surface) A, (1) should be written

$$i' = \text{Const } A \cdot B \cdot \frac{A}{f} \cdot \frac{B}{f} \cdot \frac{1}{r}. \qquad (3)$$

In order to maintain the photographic purity constant, it is necessary to have

$$\frac{A}{f} \cdot \frac{1}{r} = \frac{\beta_A}{r} = \text{Const.}$$

This may be done in either one of two ways: (1) by keeping f constant, in which case the resolving power will vary directly as A; the angular dispersion (and hence the closeness of ruling on the grating) remaining constant; (2) by keeping r constant, in which case the focal length increases and the angular dispersion decreases (the *linear* dispersion, therefore, remaining the same) in the same ratio as A is increased. In either case, if the spectra are linear (*i. e.*, not broadened either by aberration or by drift), we have, under the condition of constant purity

$$\frac{i'}{i'_0} = \frac{\epsilon}{\epsilon_0} \cdot \frac{A\,B^2}{A_0\,B_0^2} \cdot \frac{f_0}{f} \qquad (4)$$

ϵ and ϵ_0 being the "factors of efficiency" for the two spectroscope trains.

If we maintain the focal length constant and assume that ϵ and ϵ_0 will be the same for gratings ruled with the same or similar diamond points (when f is constant the grating space remains the same for Q = const.), then the intensity of the spectra (linear), from two such gratings will vary as the ratio of the aperture times the ratio of the length of the ruled lines. A grating with a ruled surface of 2.5×5 inches (area = 12.5), and having the same focal length (40 inches) and factor of efficiency, ϵ, as the one used by Professor Poor (ruled surface 1×2 inches), would consequently give a linear star spectrum about fifteen and two-thirds times more intense. It ought therefore, under the imposed conditions of constant photographic purity, to be able to photograph the spectra of second magnitude stars, which are about one twenty-third as bright as Sirius, in about an hour and a half. If the length of the ruled lines were made five inches instead of

two and a half the intensity of the *linear* spectrum would be quadrupled and, other circumstances remaining the same, the time of exposure reduced to about 25^m for a second magnitude star or to one hour for a third magnitude star.

Practically we cannot hope to do quite as well as this, because in practice all stellar spectra are broadened to a greater or less degree by the effect of irregularities of following and the effect of atmospheric disturbances. Even could these effects be avoided it would still be necessary to mechanically broaden the spectra slightly in order to avoid false lines due to imperfections in the film. If we assume that this broadening is in all cases the same, the resulting diminution in the effective photographic intensity will vary as

$$\frac{B}{f} : \frac{B_0}{f_0} = \frac{\beta_B}{\beta_{B_0}}$$

and therefore for two spectra of the same linear width the ratio of effective intensities becomes

$$\frac{i'}{i'_0} = \frac{\epsilon}{\epsilon_0} \frac{A\,B}{A_0\,B_0} = \frac{\text{Area of Grating } G}{\text{Area of Grating } G_0}. \qquad (5)$$

In this case the above computed times of exposure for the 5×5-inch grating would be increased five times, or it would require about two hours' exposure to obtain the spectrum of a second magnitude star with gratings of the maximum size now obtainable. The spectra obtained with large gratings might, perhaps, be made *somewhat narrower* than those obtained with small ones, in which case the exposure times required would lie somewhere between the two values given above. It appears therefore that it is well worth while taking up this line of work with the gratings now obtainable, although we cannot hope to work with stars much below the second magnitude until larger ones are available.

It is of interest to compare these results with those obtained with the plane wire grating used in conjunction with the 12-inch photographic objective. The surface of the wire grating is 10.5×10 inches and the area used (the corners of the grating were cut off by the circular form of the aperture), is about 100 square inches. The theoretical resolving power of the grating (first order) is 1700 and that of Professor Poor's grating, about 14,400 (first order). The horizontal angular aperture $\frac{A}{f}$ is almost the same in the two cases (slightly less in

the case of the wire grating). The photographic purity obtained with the latter is therefore 1700 : 14,400, or a little more than two-seventeenths that obtained with the former. If the two gratings were equally efficient we would have for the *same* photographic purity and the same width of spectrum the ratio of intensities

$$\frac{i'}{i'_0} = \frac{2}{100} \cdot \frac{2}{17} = \frac{1}{425} \tag{6}$$

or the 10.5-inch wire grating ought to photograph the spectra of stars of a given magnitude in about one four hundred and twenty-fifth of the time required with the 2-inch concave grating. If the width of the spectra obtained in the two cases were respectively w_0 and w this ratio would be increased or diminished in the ratio $\frac{w}{w_0}$. Taking the time of exposure required with the 2-inch grating for Sirius as 40^m with a width $w = 0^{mm}.25$,[1] the time of exposure for the wire grating for a width $w_0 = 2^{mm}.5$ (the focal length was about 18 feet, or about 5.5 times that of the 2-inch concave grating), would, if the two were equally efficient, be about 1^m for spectra of the first order and about 4^m for spectra of the second order.[2] In the table already given (p. 199) we find (G G 11), that with an exposure of three and one-third minutes, the first order spectra (width $= 2^{mm}.5$) were "overexposed," the second order "distinct but underexposed." If the development had been carried farther (see remark preceding the table) the second order could have been brought up very nearly to full density. The plates used in the experiments with the wire grating were Seed "26"; the plates used by Professor Poor are the new "Gilt Edge" Seed which the makers claim are considerably more rapid than the "26."

The computed time of exposure required by the 2-inch concave grating for β Leonis (mag. 2.2), on the basis of the exposure time required for Sirius (mag. -1.4), would be

$$40^m \times 2.51^{3.6} \cong 18 + \text{hours.}$$

The time required by the 10.5-inch wire grating would be [see (6)]

[1] Measured on one of Professor Poor's original negatives kindly sent to me for examination.

[2] In this wire grating the diameter of the wire is about equal to one-half the grating interval s, and the theoretical relation between the brightness of the different orders m_1, m_2, etc., of the grating is therefore very nearly fulfilled, *i. e.*, $i'_0 \sim \frac{1}{m^2}$.

$$T_1 = \frac{18}{425}\frac{w_0}{w} = 2.6\,\frac{w_0}{w}\text{ minutes} \qquad (7)$$
$$= 10.4\text{ minutes}$$

when $w = 0^{mm}.25$ as before and $w_0 = 1^{mm}$.

In the case of γ Leonis (G G 17) and β Leonis (G G 19), both of magnitude 2.2, about four minutes' exposure was required to obtain a first-order spectrum of full density when $w_0 = 1^{mm}$. In these cases, then, the actual times of exposure are less than 40 per cent. of the equivalent computed time for the concave grating. The earlier result (G G 10, March 21) for β Leonis is not quite as favorable. In this case $w_0 = 0^{mm}.6$ for the second-order spectrum (somewhat greater than this for the first order, because of overexposure). Hence

$$\frac{w_0}{w} = 2.4$$

and from (7)

$$\left.\begin{array}{l} T_1 = 6\tfrac{1}{4}\text{ minutes, for the 1st order}^1 \\ T_2 = 25\text{ minutes, for the 2d order} \end{array}\right\} \qquad (8)$$

The actual time of exposure was twenty minutes, and the second order was not quite fully exposed (nor was the plate quite fully developed).

Making the comparison of the computed and actual times of exposure in the same way in the cases of δ Leonis (G G 20) and ζ Leonis (G G 18), the magnitudes of which are 2.8 and 3.6 respectively, we find

$$\text{for } \delta \text{ Leonis } \frac{\text{Comp. } T_1}{\text{Actual } T_1 *} = \frac{12.6\text{ minutes}}{8.0\text{ minutes}} *$$
$$\text{for } \zeta \text{ Leonis } \frac{\text{Comp. } T_2}{\text{Actual } T_2 \dagger} = \frac{22.5\text{ minutes}}{13\text{ minutes}} \dagger$$

The case of Procyon is not directly comparable with that of Sirius, as it has a different type of spectrum.

In view of all these results it may fairly be inferred, I think, that, in spite of the absorption of the 12-inch object-glass, the efficiency of the 12-inch wire objective grating is something like 50 per cent. higher than that of the 2-inch concave objective grating.[2] The former

[1] See footnote on p. 203.

* First order somewhat overexposed.

† Second order somewhat underexposed (but plate underdeveloped).

[2] It is quite possible that this advantage would wholly disappear in comparing the wire grating with *another* ruled concave grating, with which a larger proportion of the light is concentrated in one of the first-order spectra. Professor Poor, however,

instrument would therefore seem to offer the greater promise in the future development of this line of work, both on account of its higher efficiency and on account of the greater ease of construction and much less cost of gratings of larger aperture than those at present in use. It has, however, the disadvantage of requiring a large aperture in order to obtain moderately high resolving powers. The finest wire that can be used in the construction of large gratings must have a diameter of at least $0^{in}.0015$,[1] and in order to obtain a resolving power of 15,000 units in the first order, we would have to have an aperture of at least 50 inches (if the interval were made twice the diameter of the wire). We could, however, attain practically the same *photographic* resolving power as was obtained with the 2-inch concave grating with a wire grating of 25 inches linear aperture used in conjunction with an object-glass of about 80 feet focal length (ratio of aperture to focal length 1 : 40). In any event, gratings of considerably larger aperture than the *ruled* gratings now obtainable would be the first requisite if we are to work on stars fainter than the second magnitude.

As regards the possibilities of obtaining larger ruled gratings, it has already been stated[2] that the writer has designed a ruling machine capable of ruling gratings 15 inches in diameter, the construction of which was begun some eight months ago in the instrument shops of the Observatory, and which is now well advanced toward completion. If this machine is successful in producing good gratings of the maximum size for which it is designed (ruled surface 10×15 inches), we may hope to obtain with them spectra of fourth-magnitude stars in about two hours' exposure time — about the longest exposure that we can afford to give in stellar spectroscopic work, unless temperature conditions, etc., are unusually favorable. We may, of course, do somewhat better than this by using a smaller photographic purity than that obtained by Professor Poor with the 2-inch grating (about

informs me that the grating used by him was one having an unusually brilliant first-order spectrum, the succeeding orders being so faint that only in one or two cases were there any traces of them obtained on the plate. As shown in the table, not only the second, but in many cases the third order of spectra were obtained with the wire grating.

[1] Rubens (*Wied. Ann.*, 51, 381, 1894) constructed a small grating of gold wire only about $0^{in}.001$ in diameter. Such wire, however, would be too weak to be used in the construction of large objective gratings.

[2] "On the Resolving Power of Telescopes and Spectroscopes for Lines of Finite Width," *Phil. Mag.*, May, and *Wied. Ann.*, June 1897.

$14{,}400 \dfrac{\lambda}{n\,e\,\beta} \cong 7000$ units), upon which the preceding comparisons have been based; but this does not seem desirable, if *ruled* gratings are to be used at all. Smaller resolving powers are best obtained by the use of prisms or of wire gratings, as already pointed out.[1]

In constructing concave gratings of larger size than 15 inches one of the most promising plans would seem to be to photograph the grating directly on the face of a concave silvered glass mirror, using as an original a grating having the requisite number of lines (7000 to 15,000), either ruled on glass (in which case the copy would be an enlarged one), or made of wire in the manner of the 10-inch grating already described (in which case the original would, as already indicated, be of 25 to 50 inches aperture, and the copy therefore in general a reduced one). We might photograph the grating directly on the silver surface by sensitizing the latter with iodine and bromine (thus converting it into a daguerreotype plate), or we might advantageously modify and extend the experiments begun by Lord Rayleigh a number of years ago,[2] and try photographing the grating on a thin

[1] The theoretical resolving power of the compound star spectrographs now in use in connection with our largest telescopes (the Pulkowa, Lick, and Yerkes refractors, and the Paris reflector) is not greater than 12,000 units (3 dense flint prisms of about 1-inch aperture), and the photographic resolving power is generally less than one-half of this. The highest resolving power yet used, so far as I am aware, in sustained spectroscopic and spectrographic research is that employed by Pickering in the four-prism objective spectroscope of the Harvard Observatory, which is about equivalent to a single 60° prism of light flint of 11 inches clear aperture, and which has therefore a theoretical resolving power of something like 30,000 units (in the visible part of the spectrum). (See Tables in this JOURNAL, **2**, 264, Nov. 1895.) But the focal length of the telescope on which this prism battery is mounted is only 153 inches $\left(\beta_A \cong \frac{1}{14}\right)$ and only about one-third of this resolving power is in consequence *photographically* utilized. In most of the work only one or two prisms are used, giving a practical photographic resolving power of about 2500 and 5000 units respectively (under first-class atmospheric conditions). In view of these facts it would seem desirable in taking up this line of work with the concave grating to obtain at least the photographic purity indicated above (7000 units). On the other hand, it seems extremely doubtful whether we will ever be able to fully utilize, either visually or photographically, resolving powers higher than 30,000 units in stellar spectroscopic or spectrographic research; except, perhaps, in occasional special studies of the spectra of the *very brightest* stars, or in examining and photographing *bright line* spectra.

[2] *Proc. R. Soc.*, No. 136, 1872; *Brit. Assoc. Report*, 1872; *Phil. Mag.*, **47**, 1874. The objection to the use of the lens, mentioned by Lord Rayleigh in the last of the above papers, in photographing the grating on the sensitive surface by projection, does

transparent film of bichromatized gelatine spread over the silvered surface of the mirror. If this film could be made uniform in thickness and the process properly controlled, it might be possible to produce in this way *gratings in which the central image would be nearly abolished and the brightness of the first-order spectra consequently increased nearly four times.* This highly desirable result would be brought about, for example, if the "grooves" of the grating in the developed gelatine film were approximately rectangular and had a "width" equal to half the grating space and a "depth" of

$$\frac{1}{4n}\lambda$$

n being the index of refraction of the gelatine.

It is possible, therefore, that we may in this way be able to produce large concave gratings by photography which will be considerably more efficient than either the ruled gratings or the plain wire gratings. There is, at any rate, a most promising field of experiment open in this direction.[1]

The use of gratings, both plane and concave, in place of the prism train has also been advocated for the compound spectroscope. I have myself designed and described several astronomical spectroscopes of this class,[2] but they were intended particularly for either solar work or

not hold in the case now being considered, because the *closest* ruling necessary to obtain the required resolving power will not on a 20-inch mirror *exceed* 750 lines per inch—only one-fourth the number considered by Rayleigh.

[1] In this connection it may be interesting to call attention to another line of experimentation which I have long had in mind, and which I hope will soon be taken up. The primary object of these experiments will be to determine whether the light that is brought to a focus on the photographic plate cannot be more fully utilized than it is at present, particularly in spectrographic and astrophotographic work, in which every saving of time that can be effected is of the utmost importance. One way in which it would seem that a considerable saving might be effected would be to spread the sensitive film, not on the surface of a transparent glass plate, but on the surface of a polished metallic mirror, which may be most cheaply and easily obtained by silvering, or platinizing (if silver for any reason should prove objectionable on trial) the ordinary glass plates. All the light which is now lost by passing through the film and glass would be reflected back through the film, probably nearly doubling the effective action, and thus increasing, not only the "sensitiveness" of the film, but also the "contrast" in the resulting negative. This plan would also effectually prevent all "halation."

[2] See particularly "Some New Forms of Combined Grating and Prismatic Spectroscopes of the Fixed Arm Type," this JOURNAL, 1, 232, March 1895; and "Fixed Arm Concave Grating Spectroscopes," *ibid.*, 2, 370, December 1895.

for the study of bright line (nebular) spectra. But I can see ***no good reason*** why they should be preferred to the prism train in stellar spectroscopic work, with the compound spectroscope or spectrograph, for the chief arguments for their use in the case of the objective spectroscope (*i. e.*, the avoidance of loss of light by absorption in the large object-glass, and the possibility of making absolute wave-length measurements with them without the aid of a comparison spectrum) no longer hold in this class of work. It seems to me that in this case the prism train is much to be preferred, partly on the score of greater stability, but much more because it concentrates all the light in one spectrum. We lose a great deal of light by the absorption and diffusion of the large object-glass;[1] we lose still more at the jaws of the slit by reason of the constant shifting and blurring of the image by atmospheric disturbances, and there is not so much left, even when the largest telescope and the brightest stars are at our disposal, that we can afford (as we can in the case of the Sun) to waste it recklessly in the multiplication of useless and extraneous spectra.

F. L. O. WADSWORTH.

YERKES OBSERVATORY,
January 1898.

VARIABLE STAR CLUSTERS.[1]

SINCE the announcement made in *Circular* Nos. 2 and 18, of variables discovered in clusters, a further examination of the clusters ω Centauri, Messier 3, Messier 5, and *N. G. C.* 7078 has been made by Professor Bailey. As a result, the numbers of known variables in these clusters have been increased by 62, 19, 22, and 24 respectively, making the total numbers 122, 132, 85, and 51, or 390 in all four clusters. Adding to these the 47 already announced in other clusters, makes the total number 437.

NEW VARIABLE STARS.

When a new variable star is discovered at this Observatory it is the custom to collect all the photographs of the region containing it and to derive its photographic magnitude from each of them as described in the *H. C. O. Annals*, **26**, 250. We can thus determine its bright-

[1] Much more, probably, than we subsequently lose in the prism train if the material and refracting angle (see this JOURNAL, **2**, 264, November 1895) of the elements of the latter be properly chosen.

[1] *Harvard College Observatory Circular* No. 24.

ness on from twenty to a hundred or more nights distributed over the last ten years. The approximate dates of maxima, the corresponding magnitudes, the period and the form of light curve are also determined so far as possible. Examples of such results have already been published, but every year, owing to the increasing amount of material, the work becomes more laborious although at the same time more complete and exact. Many of these stars vary irregularly so that their elements cannot be determined precisely. When the object is not a catalogue star its position, and that of each of the fainter comparison stars must also be determined from measures of their rectangular coördinates. An attempt is then made to photograph each of these variables once a month, and, if possible, to obtain corresponding observations of their visual magnitudes. As the total number of variable stars discovered here is now more than a hundred, not including those found in clusters, the labor involved in this work is very great. Accordingly, it is difficult to deduce all the required data for one star before another is found. The accompanying table gives the material that has been so far collected for the variables recently discovered here from the Draper Memorial photographs.

Constellation	Designation	R.A. 1900	Dec. 1900	Type	No. Plates	Mag.		Discoverer
						Br.	Ft.	
		h m						
Eridanus	−16° 771	3 59.8	−16° 0′	III	35	8.3	9.4	M. Fleming
Eridanus	−25° 1766	4 7.3	−25 24	III	65	8.1	<12.5	M. Fleming
Monoceros....	− 8° 1641	6 52.5	− 8 56	III	43	8.1	10.3	M. Fleming
Puppis.......	−38° 4049	8 1.7	−38 29	IV	..	...	....	L. D. Wells
Puppis.......	−22° 2160	8 3.1	−22 38	IV	..	...	....	L. D. Wells
Hydra	− 5° 2550	8 24.7	− 5 59	III	..	...	....	M. Fleming
Carina	R	10 40.9	−58 54	...	149	9.6	10.7	L. D. Wells
Virgo........	− 5° 3424	12 2.1	− 6 12	III	..	...	....	M. Fleming
Centaurus	....	13 15.1	−61 3	III	..	...	....	M. Fleming
Apus.........	*A.G.C.* 19014	13 55.6	−76 19	III	..	...	....	———
Boötes	+14° 2700	14 1.7	+13 59	III?	..	...	....	L. D. Wells
Libra	−17° 4122	14 30.3	−17 36	II ?	38	8.3	9.6	E. F. Leland
Triang. Aust..	*A.G.C.* 20554	15 4.8	−69 42	IV	85	9.1	9.8	———
Serpens	+10° 2956	16 2.5	+10 12	III	41	9.0	<11.9	M. Fleming
Ara..........	*A.G.C.* 23005	16 54.3	−54 55	IV	..	...	....	L. D. Wells
Pavo.........	*A.G.C.* 23935	17 34.7	−57 40	IV	..	...	....	L. D. Wells
Pavo.........	....	17 41.1	−62 23	III	65	9.1	<12.8	M. Fleming
Ara..........	....	17 45.7	−51 40	III	..	...	....	M. Fleming
Cygnus	+32° 3522	19 37.1	+32 23	IV	..	...	....	L. D. Wells
Pavo.........	*A.G.C.* 27560	20 3.3	−60 14	III	..	...	....	M. Fleming
Capricornus ..	*A.G.C.* 27776	20 11.3	−21 38	IV	55	8.6	10.3	———
Microscopium.	−40° 13888	20 22.6	−40 45	III	70	8.5	<12.5	M. Fleming
Capricornus ..	−17° 6181	21 1.7	−16 49	III	79	8.1	9.3	M. Fleming
Aquarius	−14° 5960	21 7.3	−14 48	III	78	8.4	9.3	M. Fleming
Indus	*A.G.C.* 29232	21 13.6	−45 27	IV	..	...	....	L. D. Wells
Andromeda...	+47° 4318	23 50.3	+48 5	III	48	9.3	9.8	M. Fleming
Cassiopeia ...	....	23 58.2	+55 7	III	101	9.8	<13.4	M. Fleming

R. A. 3^h $59^m.8$. Bright hydrogen lines suspected.

R. A. 4^h $7^m.3$. Hydrogen lines bright.

R. A. 6^h $52^m.5$. Hydrogen lines bright.

R. A. 8^h $1^m.7$. Found to be fourth type by Mrs. Fleming.

R. A. 8^h $24^m.7$. Bright hydrogen lines suspected.

R. A. 10^h $40^m.9$. This star is No. 119 on page 627 of the *Argentine General Catalogue*.

R. A. 12^h $2^m.1$. Bright hydrogen lines suspected.

R. A. 13^h $15^m.1$. Hydrogen lines bright. The position of this star for 1875 is R.A. $= 13^h\ 13^m\ 31^s$, Dec. $= -60°\ 55'$.

R. A. 13^h $55^m.6$. Bright hydrogen lines suspected. In the *Uranometria Argentina*, page 243, this star, which is θ Apodis, is stated to be variable. Discovered independently by Mrs. Fleming by means of its spectrum. The photographs show a variation of about one magnitude.

R. A. 15^h $4^m.8$. In *Argentine General Catalogue* "var.?" Discovered independently from photographic charts by Miss L. D. Wells.

R. A. 16^h $2^m.5$. Hydrogen lines bright.

R. A. 17^h $41^m.1$. Hydrogen lines bright. The position of this star for 1875 is R.A. $= 17^h\ 38^m\ 45^s$, Dec. $= -62°\ 21'.6$.

R. A. 17^h $45^m.7$. Hydrogen lines bright. The position of this star for 1875 is R.A. $= 17^h\ 43^m\ 42^s$, Dec. $= -51°\ 39'.2$.

R. A. 20^h $3^m.3$. Bright hydrogen lines suspected.

R. A. 20^h $11^m.3$. Suspected of variability by Secchi and others. Found independently from the photographs by Miss L. D. Wells.

R. A. 20^h $22^m.6$. Hydrogen lines bright. Maxima represented by formula, $2410860 + 325\ E$.

R. A. 23^h $50^m.3$. Bright hydrogen lines suspected.

R. A. 23^h $58^m.2$. Hydrogen lines bright. The position of this star for 1855 is R.A. $= 23^h\ 55^m\ 53^s$, Dec. $= +54°\ 52'.3$.

In *Circular* No. 10 the variability of $-27°$ 15202 (erroneously printed 15203) suspected by Thome was confirmed by Miss E. F. Leland. Measures of 35 photographs give the maximum brightness 8.9, minimum < 12.3.

In *Circular* No. 17 the variability of a star in R.A. $= 0^h\ 25^m.6$, Dec. $= -46°\ 58'$ (1900) is announced. Measures of 26 photographs give the maximum brightness 9.0, minimum < 12.2.

In *Circular* No. 17 the variability of a star in R.A. $= 13^h\ 31^m.1$, Dec. $= -55°\ 58'$ (1900) is announced. Measures of 42 photographs give the maximum brightness 9.0, minimum < 12.6.

In *Circular* No. 17 the variability of a star in R.A. = $20^h 8^m.5$, Dec. = $-44° 43'$ (1900) is announced. Measures of 114 plates give the maximum brightness 9.0, minimum < 11.4.

In *Circular* No. 19 the variability of a star in R.A. = $5^h 18^m.9$, Dec. = $-69° 21'$ (1900) is announced. Measures of 51 photographs give the maximum brightness 8.2, minimum 9.4.

EDWARD C. PICKERING.

January 31, 1898.

POLARIZING PHOTOMETERS.[1]

NEARLY all of the photometric measurements obtained at the Harvard College Observatory during the last twenty years have been made with modifications of three forms of photometers which are identical in principal. The first of these is described in the *Annals*, Vol. XI, Part I, and was used for the observations contained in that publication. The second, the meridian photometer, furnished the observations contained in the *Annals*, Vols. XIV, XXIII, XXIV, and XXXIV. The third photometer is described in the ASTROPHYSICAL JOURNAL, **2**, 89. In all of these instruments the star to be measured is compared directly with another star by means of a double image prism and Nicol. In the first instrument, the images of two adjacent stars are brought together by a double image prism; in the second, images of two stars, however distant, are brought together by reflecting them by prisms or mirrors into two object-glasses; in the third photometer, images formed by a large telescope, of two stars not more than half a degree apart, are brought together by achromatic prisms.

An objection to the first form of photometer is that the emergent pencils of the images compared do not coincide. Small errors may therefore be introduced by irregularities in the cornea of the eye of the observer, or if he holds his eye in such a position that a portion of one image will be cut off by the edge of the pupil. This difficulty has recently been remedied by placing a second double image prism in the focal plane of the telescope, so that it does not affect the position of the two images but makes the emergent pencils coincide. A surprising degree of accuracy may then be obtained in the measures. Comparisons of the star o Ceti with the adjacent star $-3°355$, which follows it about 10^s, have been made by Mr. O. C. Wendell with the

[1] *Harvard College Observatory Circular* No. 25.

15-inch equatorial of this observatory, on 191 nights during the last five years. Until recently, the observations were made with the first form of photometer, the emergent pencils overlapping by about two-fifths of their diameter. Generally thirty-two settings were made each night, and the mean of the differences of each pair of sets of four settings each on the first fourteen nights of observation made during the present opposition was ± 0.074 magnitudes. On the last five nights the pencils were made to coincide, as just described, and the corresponding average differences were 0.020, 0.002, 0.025, 0.022 and 0.032, mean ± 0.020. On the second of these nights, January 19, 1898, the eight measures of the difference in light of the two stars, each derived from four settings, were 4.48, 4.48, 4.48, 4.48, 4.48, 4.48, 4.48 and 4.47. Owing to variations in the transparency of the air in different parts of the sky, this degree of accordance can only be expected when stars near together are compared.

The accuracy of the results attainable with the third form of photometer is shown in the ASTROPHYSICAL JOURNAL, **3**, 281, and in the observations of U Pegasi described in *Circular* No. 23. Mr. Chandler (*Ast. Jour.*, **18**, 140), while admitting the principal conclusions given in that *Circular*, denies the reality of the small difference 0.15 between the primary and secondary minima. This quantity is so small that it doubtless could only be surely determined by the most accurate photometric measurements. The individual results derived from Mr. Wendell's observations are therefore given below. Twelve observations, each consisting of sixteen settings, were made when the star was within twenty minutes of its primary minimum. Deriving from each of these, by means of the light cure, the magnitude of this minimum we obtain on October 18, 1897, 9.89, 9.94 and 9.96; on December 30, 9.90, 9.95, and 9.93; on January 1, 1898, 9.93, 9.86, and 9.85; on January 5, 9.85, and on January 7, 9.86 and 9.88. Mean of all, 9.90, greatest value, 9.96, least value, 9.85, average deviation ± 0.035. Similarly fourteen observations were taken within twenty minutes of the secondary minimum with the results on October 18, 1897, 9.75 and 9.71; on October 29, 9.74, 9.69, 9.70 and 9.70; on December 28, 9.78, 9.77, 9.76 and 9.80; on January 3, 1898, 9.77, 9.77, 9.74 and 9.78. Mean of all, 9.75, greatest value, 9.80, least value, 9.69, average deviation, ± 0.029. It will be noticed that the largest value of the secondary minimum is 0.05 less than the smallest value of the primary minimum. If we assume that the primary and secondary minima are really equal,

all of the first of these values give positive residuals with the mean value $+0.064$, and all of the second (with one exception, $+0.01$) give negative values with the mean value -0.70. The probability that the two minima are really equal and that these deviations are due to accidental error is extremely small. It is the same as that a person should draw a red card from a pack of cards twelve times in succession, and then should draw a black card thirteen times out of fourteen. On the other hand, if these deviations are due to a sytematic error, it is very singular that this error always has one value at the time of a principal minimum, and another at the time of a secondary minimum.

EDWARD C. PICKERING.

February 8, 1898.

ON THE DEPTH OF THE REVERSING LAYER.

THE theory of the solar rotation, combined with the rotation laws empirically found for the Sun-spots, the faculæ and the reversing layer, gives a means of finding the differences in the level of these different regions of the solar atmosphere. The discussion which I have undertaken in my thesis shows these differences to be considerable, amounting to over one-tenth of the solar radius.[1] This is distinctly in contradiction to the views commonly adopted, according to which the differences in level can only be small. This latter opinion is founded upon direct observation, which seems to demonstrate that Sun-spots, photosphere and faculæ cannot differ very much in level, and that the reversing layer must be exceedingly shallow. How are these two diametrically opposite views to be reconciled? I may add that it is not only the theory of rotation which demands a deep reversing layer and great differences in level. The results of Jewell, Humphreys and Mohler are more easily explained in this way, and there is no fact which is contradictory to the hypothesis of a deep reversing layer except, apparently, the results of direct observation. But this difficulty is easily solved if we take account of refraction in the solar atmosphere. The discrepancy then entirely disappears.

While the solar atmosphere is probably inconceivably rare near the top of the faculæ, it is unreasonable to assume this to be also the case in those regions where heavy metallic vapors are certainly present according to the testimony of the Fraunhofer lines in the solar spec-

[1] *Hydrodynamische Untersuchungen mit Anwendungen auf die Theorie der Sonnenrotation*, Berlin, 1897, p. 31.

trum. There can be no reasonable doubt that, during its path among these vapors, a ray of light must suffer a sensible amount of refraction. If this is so, we shall find that the distance between two different levels of the solar atmosphere must appear very much shortened.

If μ is the index of refraction at the distance r from the center, then the observer at a great distance will see the distance r magnified in the ratio of μ to 1.[1] Now let r_1, μ_1 be the values of r and μ for the region immediately adjoining the photosphere and r_2, μ_2 for the region near the top of the faculæ. Then the distance $r_2 - r_1$ will appear to be

$$d = \mu_2 r_2 - \mu_1 r_1 . \qquad (1)$$

According to the theory of rotation $r_2 = 1.1\ r_1$ about, so that

$$d = (1.1\ \mu_2 - \mu_1)\ r_1 , \qquad (2)$$

and this may become very small, or even zero and negative, the actual value assumed by this expression depending upon the ratio $\frac{\mu_1}{\mu_2}$. Probably near the top of the faculæ we have sensibly $\mu_2 = 1$, so that to $\mu_1 = 1.09$ would correspond $d = 0.01 r_1$ instead of $0.1 r_1$. Such a value of μ_1, and even a larger one, does not seem improbable, considering the nature of the vapors. If our numbers for r_2 and r_1 are accepted, and d, the apparent distance, be actually measured, these simple equations offer a means of investigating the refractive power of the Sun's atmosphere. There is no good reason for neglecting it, as is usually done.

E. J. WILCZYNSKI.

CHICAGO, Oct. 8, 1897.

ERRATA.

THE following corrections should be made in Professor Very's articles in the December 1897 and January 1898 numbers of this JOURNAL:

Vol. VI, p. 402, for "r' = same corrected for distortion" read "R', r' = same corrected for distortion."

P. 404, equations (5) and (6) should have R' in the denominator instead of R.

P. 405, $\frac{r}{R}$ (four times at top of page and twice in first footnote) should have been primed in every case to signify that the image must be undistorted.

Vol. VII, p. 63, last line of the computation, for "$L - l' = 59^\circ\ 2'.4$" read "$l - l' = 59^\circ\ 2'.4$."

[1] WILCZYNSKI, "Schmidt's Theory of the Sun," this JOURNAL, 1, 119.

Reviews.

Ueber Gesetzmässigkeiten in den Spectren fester Körper (Second Part); F. Paschen. *Wied. Ann.*, **60**, 662, 1897.

A preliminary notice of this work was published by Paschen in this Journal in 1895, and the results of the work with iron oxide (*Wied. Ann.*, **58**, 455) were reviewed here last year by Professor Crew; some repetition of the material of that review can hardly be avoided if one is to consider carefully the work as a whole. From the beginning Paschen has had in mind the determination of the law of radiation of an absolutely black body, by more or less exterpolation of any laws which might be found to hold for other bodies of gradually increasing "blackness." Aside from this, however, he has found some surprisingly simple relations which hold with considerable exactness for the substances actually examined, and these also will be briefly considered.

He has studied the radiation from bright platinum, iron oxide, copper oxide, lampblack, and graphite both in air and enclosed in an exhausted glass bulb; the substances being either in the form of strips, or of coatings on platinum strips, and electrically heated.

The temperatures were determined by means of thermo-couples. His arrangement of fluorite prism and concave silvered mirrors for producing the spectrum was the same as previously used and described by him,[1] and his bolometer-galvanometer combination was of extreme sensitiveness.

He observed in two ways — first measuring the energy as a function of the wave-length, the temperature remaining constant, giving him the ordinary "energy curve"; second, the energy as a function of temperature, at a given constant wave-length, the so-called isochromatic curve. Besides reducing his observations to the normal spectrum by using his own dispersion curve for fluorite, he applied the following corrections to each observation of the energy: (1) each observation was divided by $\frac{d\lambda}{d\delta}$, (obtained from the same dispersion curve) to reduce to the condition of a constant wave-length interval falling on

[1] *Wied. Ann.*, **50**, 409.

the bolometer; (2) correction for loss of energy by reflection in the prism and at the concave mirrors; (3) correction for the radiation of the shutter ($t = 15°$ to $20°$ C.), to reduce to the condition of a shutter at absolute zero—*i. e.*, to obtain the entire absolute radiation of the substance under examination; (4) a correction depending on the width of slit and width of bolometer strip, to reduce to the condition of an infinitesimal slit (pure spectrum) and infinitesimal bolometer strip.

Since this correction is a very important one, and is here used for the first time, it will be well to consider the method of deriving it. Let $f(x)$ denote the energy at any point in a pure spectrum (*i. e.*, one formed from an infinitesimal slit), x the corresponding wave-length or minimum deviation, as the case may be; then the energy falling on a bolometer strip of width a whose center is at x will be

$$\int_{x-\frac{a}{2}}^{x+\frac{a}{2}} f(x)\, dx$$

But if the slit be so widened that its monochromatic image has a width a (the condition of Paschen's experiments), the strip will be just covered by an image of intensity $f(x)$, and will also receive energy from neighboring images whose centers are at $x+v$, $x-v$, etc., up to the images whose centers are at $x+a$, $x-a$; so that the total energy falling on the strip will be

$$F(x) = \int_{v=o}^{v=a} \frac{a-v}{a} \left\{ f(x+v) + f(x-v) \right\} dv$$

It remains to express $f(x)$ in terms of $F(x)$ and a so that it can be obtained from the observed $F(x)$; this has been done by Professor C. Runge, who has developed $f(x)$ in the form of a series. If $F(x)$ is known in the form of a curve, as in the present case, the form of the series which is most convenient is

$$a\, f(x) = F(x) - \frac{1}{6} F_1(x) + \frac{2}{45} F_2(x) - \cdot \cdot \cdot$$

$$\text{where } F_1(x) = \frac{F(x+a) + F(x-a)}{2} - F(x)$$

$$F_2(x) = \frac{F_1(x+a) + F_1(x-a)}{2} - F_1(x)$$

$F_1(x)$ is obtained very simply from the curve of $F(x)$, as is made evident by drawing the chord connecting the points $F(x+a)$ and $F(x-a)$ of the curve; $F_2(x)$ is obtained in the same way from the curve expressing $F_1(x)$ as a function of x. The actual corrections were obtained from the curve of observed energy, $F(\delta)$, plotted against observed minimum deviation (δ); the first correcting term was usually all that it was necessary to use. As an example of the amount of this correction it is mentioned that in the case of one iron oxide curve at 1100° C., ordinates near the maximum are increased by from 1 to 2 per cent. of their value, while farther down on the short wave-length side, where the curvature is greatest, they are decreased by from 5 to 10 per cent.

In plotting and discussing his results Paschen prefers logarithmic expressions; that is, if λ is any wave-length and J the corresponding energy, he replaces λ by $\log \lambda$, and J by $\log J$; or he plots $\log \frac{\lambda}{\lambda_m}$ against $\log \frac{J_m}{J}$, where λ_m is the wave-length having the maximum energy J_m; this has the disadvantage, as he remarks, of exaggerating the errors at the ends of the curves and reducing them at the center. The equation which Paschen finally adopts as most nearly representing all his energy curves is

$$J = c_1 \lambda^{-a} \epsilon^{\frac{-c_2}{\lambda T}} \tag{1}$$

where $J=$ energy corresponding to any wave-length λ,

$T=$ absolute temperature,

c_1, c_2, a are constants.

If J_m be the maximum energy, and λ_m the corresponding wave-length, it follows from the above equation that

$$\lambda_m \, . \, T = c \quad \text{where } c = \frac{c_2}{a} \tag{2}$$

$$J_m = c' \, T^a \quad \text{where } c' = c_1 \, . \, c^{-a} \, . \, \epsilon^{-a} \tag{3}$$

$$\frac{J}{J_m} = a \left\{ \log \epsilon - \frac{\lambda_m}{\lambda} \log \epsilon - \log \frac{\lambda}{\lambda_m} \right\} \tag{4}$$

$$\lambda_m = \frac{(\log \lambda_2 - \log \lambda_1) \, \lambda_1 \, \lambda_2}{(\lambda_2 - \lambda_1) \log \epsilon} \tag{5}$$

where λ_1, λ_2 are any two wave-lengths on opposite sides of the maximum corresponding to equal energies of radiation,

$$\log J = \gamma_1 - \gamma_2 \frac{1}{T} \tag{6}$$

$$\text{where } \gamma_1 = \log c_1 - a \log \lambda$$

$$\gamma_2 = \frac{c_2 \log e}{\lambda}$$

Equation (1) is of particular interest because it is of exactly the same form as that deduced by Wien[1] from purely theoretical considerations for the case of an absolutely black body, except that in Wien's case $a = 5$. The relation (2) was given by Paschen three years ago in this JOURNAL, and criticised by Very; whether this be a universal relation or not, it is true within 4 per cent. or 5 per cent. for all the substances Paschen examined, except bright platinum, for an extreme temperature range of about 900° C.— from 100° to 1000°. For bright platinum the relation is more nearly $\lambda_m T^{0.8642} = c$. Equation (3) gives a means of determining a, as does also equation (4), and the two values do not as a rule agree very well. Equation (4) expresses the property of congruency, which can also be shown by plotting log λ against log J, and then shifting the curves parallel to the coördinate axes till the maxima coincide, when they are found to quite closely overlie each other. Assuming this property of congruency to be strictly true, it furnishes a convenient means of filling out absorption bands and incomplete curves; and it is by the use of this and equation (2) that Paschen attempts to determine the energy spectrum of his shutter at a temperature of about 19° C., with which he reduces his observations to the condition of having a shutter at absolute zero. This has been criticised by Dr. H. F. Reid, who points out that since all observations of radiant energy are observations of differences— between the radiation of the given source and of the shutter used to exclude this radiation, the curves for which the property of congruence has been deduced are difference curves, and the assumed zero line is really the absolute radiation curve of the shutter. If this shutter radiation curve is very near the true zero line (*i. e.*, if the correction for the shutter is everywhere small) then we will be justified in assuming as a first approximation that the observed energy curves are the true absolute radiation curves, in exterpolating any relations which we may find to hold for high temperatures, down to the temperature of the shutter, and in applying the curve obtained by exterpolation as a

[1] *Wied. Ann.*, **58**, 662.

correction to the observed curves. In doing this, then, we virtually assume at once that the radiation of the shutter is very small in comparison with that of the source; it seems possible, therefore, that even Paschen's corrected curves may fall considerably short of representing the true entire radiation of his source, at least for the lower temperatures. Equation (5) is used by Paschen to obtain the value of the wave length of maximum energy; it having been found to give results agreeing with each other to within about 1 per cent. for pairs of wave-lengths (λ_1, λ_2) as much as 4^μ apart. Equation (6) expresses the (straight line) variation of J with T, λ being fixed (isochromatic); this straight line relation is badly fulfilled, perhaps because the correction for width of slit and bolometer strip was not applied to these observations. These isochromatics, however, plotted in another way, satisfy fairly well a condition of congruency somewhat similar to that of the energy curves.

As to the constants in the above formulæ, c is largest for one of the graphite strips in a glass bulb, and least for bright platinum; α can be obtained either from the form of the energy curves or from equation (3), and these two values always differ, sometimes by a considerable amount. For Pt, FeO, CuO, and lampblack, $\alpha = 5.58$ about, and for carbon in bulb, about 5.09, determined by the form of energy curves; determined by equation (3) the values are quite irregular. Paschen attempts to arrange these substances in the order of their "blackness," which would probably be the same as the order in which they arrange themselves with respect to the total energy radiated, since an absolutely black body radiates more (or as much) energy of every wave-length as any other body. The total energy he obtains by integrating the above expression for J; from this comparison it would follow that for low temperatures one of the graphites in a bulb is the "blackest," while for high temperatures (900° to 1100° C.) iron oxide is the blackest. He concludes that the energy curve of an absolutely black body will be found to satisfy equation (1) with $\alpha < 5.24$, c at least 2600, c_2 about 14,000; and there is at least no experimental objection to the view that α may become 5, as required by Wien's formula.

From the behavior of graphite in a bulb, Paschen is led to investigate analytically the radiation which would be found inside an inclosure having reflecting walls and containing a radiating body at a uniform temperature, which reflects diffusely. He finds that the result-

ing radiation would be the nearer to that of an absolutely black body the better the reflecting power of the walls; so that for such a good reflector as silver, the departure of this radiation from that of an absolutely black body would be, at $0^{\mu}.6$, only 0.17 per cent., and less for longer wave-lengths which are more perfectly reflected; and that under these conditions the position of the radiating body with respect to the walls of the inclosure becomes of secondary importance. Following up this idea, he intends to investigate the radiation from a blackened platinum strip inclosed in an internally silvered glass bulb. As a method for realizing the radiation of an absolutely black body, this seems to offer great advantages in the way of simplicity and ease of manipulation, and the results of his study will be looked for with great interest.

C. E. MENDENHALL.

JOHNS HOPKINS UNIVERSITY,
February 14, 1898.

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CONDUCTED BY

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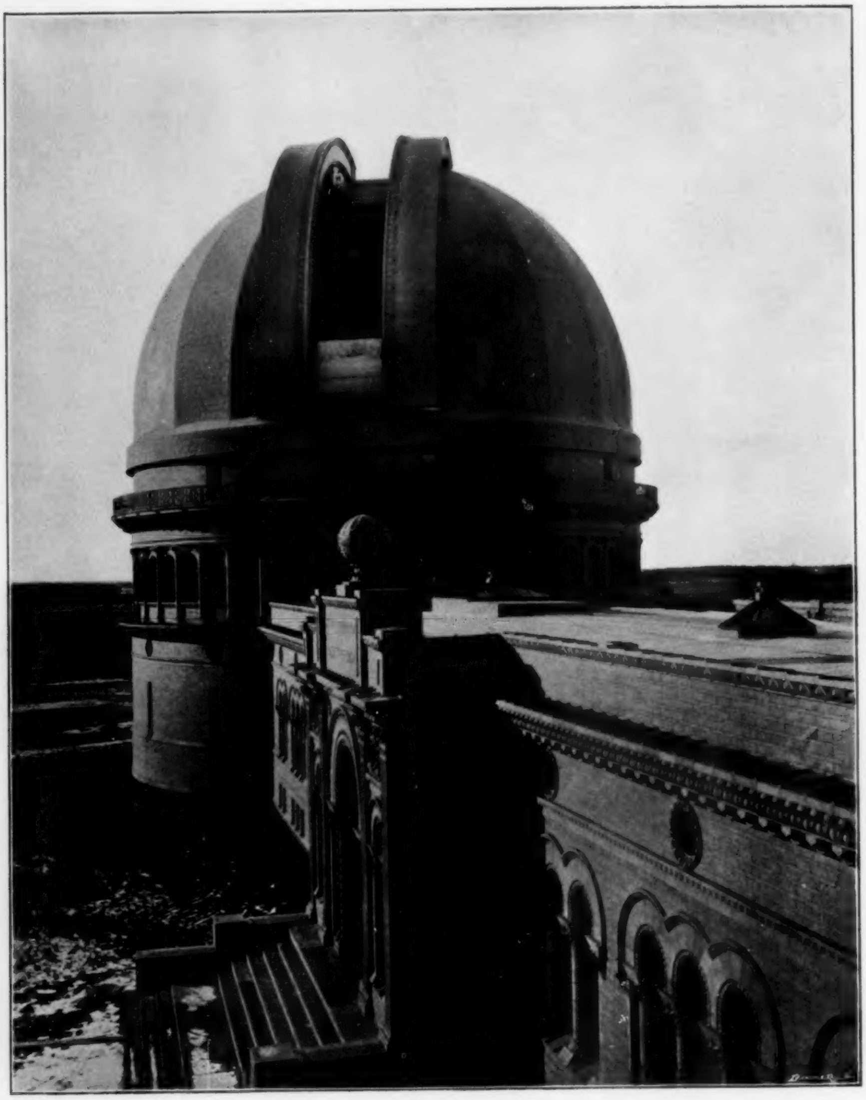

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